Residential customers and adoption of solar PV

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Abstract

The recent surge in uptake of solar PV has changed the energy supply and demand paradigm with consumers now being both users and producers of electricity. Policies that encourage the adoption and use of solar PV have a number of social, economic and environmental aspects and the role of the consumer is important in ensuring these policies are effectively targeted. Whilst there is significant research regarding technical aspects of solar PV adoption, the literature examining the consumer's perspective about this topic is still in its early stages and only one Australian study based on primary research of consumers has been identified.

To maximise the benefits from policies that encourage solar PV, it is vital to understand the role of the consumer as their adoption and use of this type of technology may, or may not, align with policy objectives. The purpose of this thesis is to elucidate, from a customer perspective, the profile of consumers who acquired solar PV under different policy settings and whether the acquisition of this technology prompted changes in consumer behaviour with respect to energy use. This thesis examines similarities, differences and gaps in the existing literature on consumer engagement with solar PV. It also employs both quantitative and qualitative methods to examine the current profile of solar PV adopters and their lived experiences of acquiring and using solar PV.

The research for this thesis is based on a mixed method approach using a quantitative (Study One) and qualitative (Study Two) analysis of consumers and their acquisition and use of solar PV. Study One utilised existing multi-sourced quantitative secondary data to develop profiles of consumers at annual intervals from 2010 to 2014 to examine the uptake of solar PV programs based on selected demographic data. The triangulation of the socio-economic (explanatory variables) from the quantitative data, using different analytical methods including Classification and Regression Tree (CART) and Boosted Regression Tree (BRT), enabled the development of a comprehensive profile of solar PV consumers and

the examination of whether these explanatory variables are inter-related. In addition, these different analytical methodologies were used to investigate whether the profile of solar PV consumers changed over time and under different policy settings.

Study Two was a qualitative explorative field study, using semi-structured in-depth interviews with 22 participants divided into two cohorts based on whether they received a $0.44 feed-in tariff (FiT) offered from 2008 to July 2012 or a lesser $0.06 FIT offered after July 2012. This research took a qualitative phenomenological approach based on participants' own words and voices in expressing and understanding their day-to-day lived experiences.

For policy makers, the findings from this research indicate the complexity of the profile of consumers adopting solar PV; how this profile changed over time and under different policy settings; and how consumer responses regarding their use of solar PV may have significant policy ramifications. Previous literature has not identified any similar studies examining solar PV or consumers of solar PV under circumstances of changing policies and incentives.

This thesis contributes to knowledge through the combination of an innovative quantitative method and a further qualitative examination of consumer adoption and use of solar PV technology that is transforming the energy sector. This is the first time CART and BRT methods have been employed to investigate this complex statistical problem. The triangulation of different analytical methods enabled the development of a comprehensive profile of solar PV consumers and the examination of the inter-relationship of these explanatory variables. Study One (Paper Two) identifies that explanatory variables for solar PV uptake are complex and inter-connected and that these variables change under different policy settings.

This thesis shows that the profile of solar PV consumers changed under different policy settings and should be continuously reviewed to capture the changing demographic profile of solar PV consumers. In addition, any such profile of consumers should be cross-verified through different analytical methods such as those described in this thesis. The findings from this research indicate the important linkages between demographic explanatory variables in solar PV uptake and this is an important finding for informing the development and analysis of future solar PV policy.

The findings from Study One (reported in Paper Two), while significant, provide only part of the information needed to inform the development and analysis of domestic solar PV policy so that it has the best opportunity of achieving stated outcomes. This thesis also examined consumer interaction with two different solar FiT policies from 2010 to 2014 (Paper Three) and identified a number of issues of significance raised by consumers that could impact upon the objectives of solar PV policies. The responses from consumers receiving a $0.44 FiT indicated they changed behaviours to optimise financial returns from their solar PV which should be further examined to quantify potential negative consequences on overall energy policy, and in particular, policy designed to manage peak demand. The responses from consumers receiving a $0.06 FiT indicated they changed behaviours to optimise use of solar PV to reduce demand for electricity from the grid. This should be further examined to quantify the potential positive impact on general energy policy aimed at increasing the use of solar PV to reduce demand for electricity during network peak times and from sources that produce greenhouse gases.

This thesis shows that to maximise the benefits from policies that encourage solar PV, the role of the consumer is critical as their use of renewable energy technology may, or may not, align with policy objectives of the energy professionals. The contribution of this research is that it provides a better understanding of consumer interaction with solar PV technology. From this understanding, policy options can be developed and/or adapted to address technical and/or human-related issues that impact on the effectiveness of solar PV policy aimed at reducing peak demand and creating low carbon communities.

List of publications

1. Journal articles presented as part of this thesis

Chapter 2: Sommerfeld, J. & Buys, L. (2014) Australian consumer attitudes and decision making on renewable energy technology and its Impact on the transformation of the energy sector. *Open Journal of Energy Efficiency*, 3, 85-91. doi: http://dx.doi.org/10.4236/ojee.2014.33009

Chapter 4: Sommerfeld, J., Buys, L., Mengersen, K. & Vine, D. (2016). Influence of demographic variables on uptake of domestic solar photovoltaic technology. Submitted on 2 April 2015 to: *Renewable & Sustainable Energy Reviews*. Current revision submitted on 8 February 2016, Impact Factor 5.901.

Chapter 5:

Sommerfeld, J., Buys, L., & Vine, D. (2016). Residential consumers' experiences in the adoption and use of solar PV. Submitted to: *Energy Policy*, Impact Factor 2.696. Submitted on 16 May 2016.

2. Publications during candidature on related topics but not included in this thesis

Buys, L., Aird, R., van Megen, K., Miller, E, & Sommerfeld, J. (2014). Perceptions of climate change and trust in information providers in rural Australia. *Public Understanding of Science*, *23*(2), pp. 170-188. doi: http://dx.doi.org/10.1177/0963662512449948

Cockfield, G., Maraseni, T., Buys, L., Sommerfeld, J., Wilson, C. & Athukorala, W. (2011). *Socioeconomic implications of climate change with regard to forests and forest management. Contribution of Work Package 3 to the Forest Vulnerability Assessment,* National Climate Change Adaptation Research Facility, Gold Coast.

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List of abbreviations

ABS	Australian Bureau of Statistics
AEMC	Australian Electricity Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AGCER	Australian Government Clean Energy Regulator
BRT	Boosted regression tree
CART	Classification and regression tree
CEFC	Clean Energy Finance Corporation
CER	Clean Energy Regulator
EDSM	Electricity Demand Side Management
FiT	Feed-in-tariff
GHG	Greenhouse gas
GWh	Gigawatt hour
kWh	Kilowatt hour
LGCs	Large-scale Generation Certificates
LRET	Large-scale Renewable Energy Target
MAC	Marginal abatement cost
MRET	Mandatory Renewable Energy Target
MWh	Megawatt hour

NEO	National Electricity Objective
NER	National Electricity Rules
NSP	Network Service Providers
PhD	Doctorate of Philosophy
PV	Solar Photovoltaic
PVRP	Photovoltaic Rebate Program
REMODECE	Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe
RES	Renewable energy sources
RET	Renewable Energy Target
SES	Socio-economic status
SHCP	Solar Homes and Communities Plan
SRES	Small-scale Renewable Energy Scheme
STCs	Small-scale Technology Certificates
TBL	Triple Bottom Line
TJ	Terajoule

Statement of Original Authorship

I hereby declare that, to the best of my knowledge and belief, this thesis entitled "**Residential customers and adoption of solar PV"** is my own original work.

The work contained in this thesis has not been previously been submitted to meet requirements for an award at this or any other higher education institution. Due acknowledgement to each significant contribution to, and quotation in this thesis from the work, or works of other people has been made through the proper use of citations and references.

30 August, 2016

QUT Verified Signature

(Jeff Sommerfeld)

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Chapter 1: Introduction

1

Anthropogenic climate change resulting from greenhouse gas (GHG) pollution has been identified by scientific findings to be a major issue for humankind (Flannery & Sahajwalla, 2013). The response by governments around the globe to put in place measures that reduce (GHG) pollution (Buckman & Diesendorf, 2010) has emanated from this concern. A range of policy options have been advocated with a focus on supporting efforts to increase the use of renewable energy sources (RES) to reduce the long-term reliance on carbon emitting fossil fuels (Batel, Devine-Wright & Tangeland, 2013; Mills & Schleich, 2009). The success of policies that encourage the uptake of renewable energy requires consumer acceptance and engagement with new and emerging energy technologies such as solar photovoltaic (Devine-Wright, 2007; Sauter & Watson, 2007; Willis, Scarpa, Gilroy & Hamza, 2011; Sardianou & Genoudi, 2013).

Australia is the largest per capita greenhouse gas (GHG) emitter in the Organisation for Economic Cooperation and Development (OECD), with electricity generation accounting for more than 30% of GHG emissions (Buckman & Diesendorf, 2010). The ability to generate electricity from a renewable source, such as solar photovoltaic (PV), is seen as a crucial transformation of the electricity sector towards reducing Australian GHG emissions (Buckman & Diesendorf, 2010). Australia has one of the highest average solar irradiation levels of any continent in the world, with a 1 kW household solar photovoltaic (PV) system having an average generation potential of 1460 kWh per annum (Chapman, McLellan & Tezuka, 2016).

In recent years, there has been a rapid expansion of renewable energy derived from rooftop solar PV systems in Australian households. This expansion reflects concern about rising electricity prices together with Commonwealth and State government policies and subsidies, which have been provided for different types of solar energy products. Table 1.1 summarises the growth of domestic solar hot water and solar photovoltaic (PV) systems since 2001. In 2007, solar PV systems represented 9.6 MW of a 50,000MW power grid and in just four years, this increased by 100-fold to 1031 MW (Nelson, Simshauser & Nelson, 2012).

Table 1.1: Small Scale Solar Installations 2001 to 2014

Installation year	Solar PV systems	Solar water heaters	Total
2001	118	10,075	12,194
2002	251	21,839	24,092
2003	664	28,653	31,320
2004	1,089	30,991	34,084
2005	1,406	33,964	37,375
2006	1,115	35,924	39,045
2007	3,480	50,977	56,464
2008	14,064	85,385	101,457
2009	62,916	194,695	259,620
2010	198,208	127,093	327,311
2011	360,745	105,050	467,806
2012	343,320	69,466	414,798
2013	196,429	55,189	253,631
2014	28,788	6,801	37,603
Grand total	**1,212,593**	**856,102**	**2,068,695**

Source: Clean Energy Regulator 2014

Polices that promote solar PV have resulted in almost 11 per cent of the Australian population (about 2.6 million people) now using solar for their electricity. Queensland has the largest number of solar PV installations of any state, followed by New South Wales and Victoria (Flannery & Sahajwalla, 2013). In South East Queensland, one in four detached homes have rooftop solar PV (Energex, 2015).

Solar photovoltaic (PV)

First patented in 1954 (Peters, Schneider, Griesshaber & Hoffmann, 2012), the solar cell has, in the past decade, emerged as a major alternative source of electricity generation. Solar PV systems convert light energy directly into electricity by transferring sunlight photon energy into electrical energy, whereas solar hot water systems use solar radiation to heat water (Bahadori, 2013; Macintosh & Wilkinson, 2011). For 20 years, State and Commonwealth government policies have focused on reducing the cost of solar technologies for consumers, and encouraging their uptake. These policies focused on support for different types of technologies, including rebates for solar water heating systems and feed-in tariffs (FiTs) for residential PV installations (Bahadori, 2013). In 2001, the Australian Government introduced the Mandatory Renewable Energy Target (MRET) scheme to encourage investment in renewable energy technologies (Kuwahata & Monroy, 2011). The scheme was split in 2010 into two parts: the Large-scale Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES). During this period, the Australian Government provided rebates to householders who acquired solar PV systems; this was called the Photovoltaic Rebate Program (PVRP), which was rebranded in 2007 as the Solar Homes and Communities Plan (SHCP) (Macintosh et al., 2011). The SRES provided a fixed upfront incentive of about $5000 to reduce the capital cost of solar PV technology, while most States and Territories offered the owners of small-scale solar PV installations a feed-in-tariff (FiT) that paid households for electricity generated (Nelson et al., 2012).

As a result of government policies and incentives and ensuing consumer demand, Australia has one of the highest rates of solar PV adoption in the world, (Simpson & Clifton, 2015). By the end of 2012, Queensland, known as the “Sunshine State”, had the highest up-take of solar, with almost one-third of all PV capacity in Australia (Flannery et al., 2013; Chapman et al., 2016). From 2008 to 2012, public policy in Queensland provided additional incentives for consumers to acquire solar PV through a solar FiT of $0.44, equalling $440 MWh (Nelson et al., 2012). Consumers were also eligible for the national SRES rebate (Macintosh & Wilkinson, 2011). In July 2008 there were 533 solar PV installations in south east Queensland, a number which grew to 157,849 by July 2012 (Table 1.2). In July 2012 a significant policy change occurred, with the Queensland Government-guaranteed solar FiT reduced to $0.08. A further change occurred in July 2014, when the solar FiT became determined by the market at approximately $0.06 for each kilowatt of power exported to the grid.

Table 1.2 Domestic solar PV south east Queensland 2008 to 2014

Installation year	Solar PV systems
As at July 2008	533
As at July 2009	5947
As at July 2010	27,100
As at July 2011	83,188
As at July 2012	157,849
As at July 2013	229,439
As at July 2014	264,807

Source: Energex 2015

The focus on solar PV technology in the past decade has seen the price per PV unit decrease significantly. Since July 2012, the policies that encouraged the rapid uptake of solar PV have changed. Commonwealth Government subsidies and State Government solar FiTs have been reduced, although the adoption rates in Figure 1.2 indicate consumers are still acquiring solar PV under policies that provide lesser subsidies and benefits.

Evaluations of solar PV policies have identified a range of issues that have arisen from the recent encouragement of solar PV. These include increases in the costs of electricity to consumers to fund solar FiTs; equity issues, with only some sections of the community able to participate; and additional infrastructure costs to prevent network instability due to the solar PV feeding electricity back into the grid (Byrnes, Brown, Foster & Wagner, 2013; Grösche & Schröder, 2014; MacIntosh & Wilkinson, 2011; Nelson, Simshauser & Kelley, 2011). Many of the issues that have arisen from the upsurge in consumer demand for solar PV, and the resultant behaviour to maximise FiTs, relate to policies that sought to promote economic aspects to grow the solar PV industry rather than environmental or social aspects that may result from these policies (Byrnes et al, 2013; Grösche & Schröder, 2014). If solar PV is to be promoted through future policies, there is a need to understand the different types of solar PV users and to identify the policy settings necessary to mitigate adverse consequences.

The policy outcome of encouraging consumers to acquire solar PV was to increase the amount of renewable electricity and reduce reliance on electricity from the grid associated with GHG emitting power stations. Whole-of-system reviews (Macintosh et al., 2011; Nelson, Simshauser & Kelley, 2011) criticised the Queensland policy as being environmentally ineffective and costly. However, these reviews focused on the carbon abatement resulting from the cost of the policy, with no examination of consumer outcomes or impacts. Socially, the move towards alternative energy sources such as solar PV has major ramifications for government policy, given the impact on consumers least able to afford these new technologies (Byrnes, Brown, Foster & Wagner, 2013; Grösche & Schröder, 2014; MacIntosh & Wilkinson, 2011).

Understanding consumer uptake and use of solar PV

Prior to the surge in uptake in solar PV in Australia, a study of UK consumers looked at the reasons for adoption or non-adoption of renewable energy and energy efficiency measures (Caird, Roy & Herring, 2007). This research drew together previous quantitative surveys of consumers from the UK, USA and Australia, on attitudes to renewables and barriers to installing them. These surveys found the main drivers to installation were environmental concern and saving money, whilst the main barriers were capital cost and lack of trustworthy information or reliable brands. It was concluded that research tended to focus on addressing financial, regulatory and information barriers and drivers.

Many of the past examinations of solar PV policy have been based on statistical data that identified consumer issues such as financial capacity, home ownership status and education (Byrnes et al., 2013; Grösche & Schröder, 2014; MacIntosh & Wilkinson, 2011). However, there appears to be little investigation into consumer motivation to adopt and use solar PV that may provide insight into how consumer behaviour may impact on the successful outcomes of public policy. Moreover, other demographic variables may also be important, such as size of family and age of residents, particularly for specific population groups. Importantly, there is a lack of quantitative analyses of the different demographic explanatory variables linked to renewable energy policies and how these may adapt over time. The literature on residential solar adoption, while growing, is still in its early stages (Rai, Reeves & Margolis, 2016). The only Australian study identified from a qualitative perspective was undertaken by Hampton and Eckermann (2013) who reported on qualitative workshops in 2005 and 2012 that examined knowledge and understanding of solar PV and renewable energy products. Despite the awareness of the general importance of socio-economic variables that have arisen from these reviews of solar PV policy (MacIntosh & Wilkinson, 2011), there remains a knowledge gap about individual and combined impact on the effectiveness of solar policies. The examination of previous research on consumer attitudes to domestic rooftop solar PV identified that consumer motivators to acquire solar PV were mostly based on economic considerations more than social or environmental issues and that previous research did not capture the complexity of consumer decision-making regarding renewable energy.

Personal motivations for this study

One of the key motivations for this research was the personal and professional engagement with solar PV technology and policy experienced by the author of this thesis, which was not reflected in the research or literature. This assessment was also reinforced by the case study context for this study (please see Appendix A), which identified issues that were also not reflected in research and previous literature. These issues highlight that:

- past domestic rooftop solar PV policies may have encouraged behaviours that did not optimise GHG abatement, as persons acquiring solar pre-July 2012 made these decisions based on financial aspects of electricity costs more than the use of solar PV for household needs;
- persons acquiring solar post-July 2012 would be more likely to use solar for household needs; and
- behavioural change is an important concept in maximising value from solar PV.

Research problem

Over almost forty years, there have been numerous studies into consumer use of energy. Disciplinary perspectives, including economics, engineering and sociology, anthropology and psychology, have delivered frameworks, theories and designs of interventions to change the behaviours of residential electricity customers (Stephenson, Barton, Carrington, Gnoth, Lawson & Thorsnes, 2010; Keirstead, 2006; Wilson & Dowlatabadi, 2007). The recent surge in uptake of solar PV has changed the energy supply and demand paradigm with consumers now both being users and producers of electricity. Policies that encourage the adoption and use of solar PV have a number of social, economic and environmental aspects and the role of the consumer is important in ensuring these policies are effectively targeted. Research examining these policies has been focused on technical, regulatory and information issues rather than the consumer adoption of solar PV technology (Caird et al., 2007).

The rapid uptake of technology by consumers has not only transformed the demand and supply dichotomy but also social and economic aspects of the electricity market. In Germany, a significant adopter of domestic solar PV, researchers identified socially regressive aspects of solar policies that resulted in the transfer of income from lower socio-economic groups to higher socio-economic groups (Grösche & Schröder, 2014). These policies provided incentives for uptake of solar PV technology that was funded from all consumers, but only higher socio-economic groups were found to have access to knowledge and capital to enable them to own this new technology.

In a review of home energy consumption research over 30 years, Crosbie (2006) suggests there needs to be an integration of quantitatively based behaviour modelling with more recent socio-technical qualitative studies. She suggests that research findings will be most powerful if nuanced with detailed sociological and ethnographic accounts of consumers' everyday practices and combined with longitudinal and detailed measurements associated with consumer and behaviour work. As the role of the consumer transforms, there is a need to understand how the consumer will engage future energy policy in an era of technological change. Much of the research into the uptake of energy technology has been identified as being narrowly focused and mostly confined to whole-of-system reviews that may limit the ability of policy makers to make informed decisions (Faiers, Cook & Neame, 2007). Social context is important in understanding consumer energy behaviour. Previous sociological and anthropological research into consumer energy use adoption and behaviour has suggested consumer motivations are more complex (Caird et al., 2007).

Research question

The purpose of this thesis is to elucidate, from a customer perspective, the profile of consumers who acquired solar PV under different policy settings and whether the acquisition of this technology prompted changes in consumer behaviour with respect to energy use. The primary question of this research is: **What is the experience of residential customers who decide to adopt and use solar PV in south east Queensland?** The supplemental questions that arise from this are: What is the profile of customers of domestic rooftop solar PV in south east Queensland?; What are the inter-related factors that motivate consumers to acquire solar PV?; What are the lived experiences of the people who acquired and are using solar PV and how do these lived experiences provide insight into understanding solar PV policy from the residential customer perspective?

Understanding the profile of consumers engaging with solar PV policy and how they engaged with the technology was the overarching goal. The research aim is to analyse the different layers and dimensions of socio-economic data and participant interviews that combine together to provide insight into the application of public policy and its effectiveness.

Theoretical approach

The theoretical lens underpinning this thesis is Diffusion of Innovation Theory. Diffusion Theory was first discussed in 1903 by the French sociologist, Gabriel Tarde (Toews, 2003), and was later adapted by Ryan and Gross (1943), who introduced the adopter categories (Figure 1.1) that are the basis for the current theory, first published in 1962 by Everett M. Rogers (2003). Its robustness derives from the wide range of fields of study, technologies and ideas, in which diffusion has been studied (Wilson & Dowlatabadi, 2007).

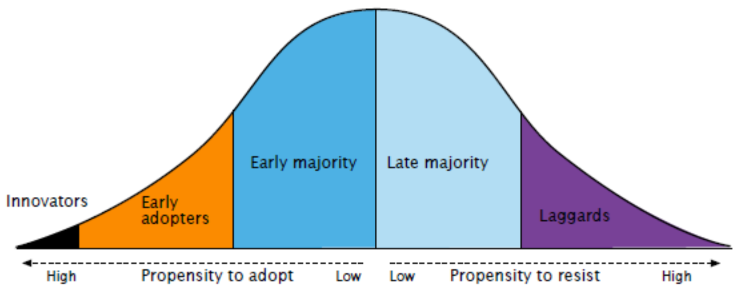

Figure 1.1 Diffusion of Innovation S curve (Robinson, 2009)

Diffusion of Innovations Theory seeks to explain how innovations are taken up in a population. Under *Diffusion of Innovation Theory,* consumers are broken down into five different segments, based on their propensity to adopt an innovation: innovators, early adopters, early majorities, late majorities and laggards. Sometimes, a sixth group is added, non-adopters (Robinson, 2009). Rogers (2003) assigned approximate percentages for each segment:

Innovators:	2.5%
Early Adopters:	13.5%
Early majority:	34%
Late majority	34%
Laggards	16%

Diffusion research often relates to technological innovations such as solar PV. Many innovations require a lengthy period from the time they become available to the time they are widely adopted (Rogers, 2003). As discussed previously, the first solar cell was patented in 1954 (Peters et al., 2012) and only in recent years has there been an upsurge in its diffusion. Rogers (2003) defines diffusion as “the process in which an innovation is communicated through certain channels over time among the members of a social system”. Innovation is defined as an idea, practice, or object that is "perceived as new by an individual or another unit of adoption" (Robinson, 2009).

Diffusion theory is a lens to explore how individuals make decisions, which can provide an important guide for researchers and policy makers concerned with the impact of human energy-use behaviour (Brewer & Stern, 2005). Solar PV uptake is often described using categories from Diffusion of Innovation Theory, as many of the consumers who acquired solar PV prior to 2008 are described as innovators. The application of diffusion of innovation theory is valuable for policy development in the understanding of solar PV adopters and their decision-making process, as there are possible positive and negative policy outcomes in the adoption and energy use of solar PV (Rogers, 2003).

In reviewing previous research and literature, the author will delineate the differing stages of adoption through the lens of Diffusion of Innovation Theor*y.* Thus, this theory is used to contextualise the findings and build upon them based on the phases of technological adoption.

Significance

Developing policies that encourage residential consumers to utilise solar PV and reduce GHG emissions is of practical importance and has long-term economic, social and environmental benefits. To maximise the implementation of these policies, the role of the consumer is critical as the use of solar PV technology may, or may not, align with policy objectives of the energy professionals (DeCicco, Yan, Keusch, Munoz & Neidert, 2015). The research and analysis of consumers and their interaction with solar PV policy is important in assessing policy outcomes and how they can be delivered or adapted (Greene, 2013). There has been limited research into the policies that encourage the uptake by consumers of solar PV and subsequent energy-use behaviour, despite the scope and variability of public policy that has underpinned domestic solar PV.

The major significance of this research is the combination of an innovative quantitative method and a further qualitative examination of consumer adoption and use of solar PV technology that is transforming the energy sector. The triangulation of the socio-economic (explanatory) from the quantitative data, using different analytical methods, enables the development of a comprehensive profile of solar PV consumers and the examination of whether these explanatory variables are inter-related. The new knowledge from this research is gained from the examination of the inter-relationship between explanatory variables that may influence a consumer to acquire solar PV under different policy settings. Using these different analytical methodologies, this study investigates the profile of solar PV consumers and how this profile may change over time and under different policy settings. Despite the awareness of the general importance of socio-economic explanatory variables that has arisen from previous reviews of solar PV policy, there remains a knowledge gap about the individual and combined impact of these variables and how they inter-relate to the objectives of solar PV policies.

The other significant innovation of this thesis is the qualitative examination of solar PV adopters and users and how they acquired and used solar PV under different policy settings. Previous literature has not identified any similar studies examining solar PV consumers under changing policies and incentives. This approach also allowed for the innovative exploration of consumer experiences with solar PV and any behavioural changes in relation to the installation of solar PV technology, to examine issues that have not been previously explored in literature or research. The practical significance of understanding consumer use of solar PV is that new knowledge provides insight into positive or adverse impacts on solar PV policy objectives. This will provide an important contribution towards the development and future design of more effective and equitable domestic solar PV policies.

Structure of the relationship between chapters and publications in the thesis

The relationship of the chapters to the thesis is depicted in Figure 1.2 below. In the first section, Chapter One provides the research context for this study. Chapter Two is a literature review, which has been submitted and accepted for publication. Chapter Three, outlines the method used for the research undertaken for this study.

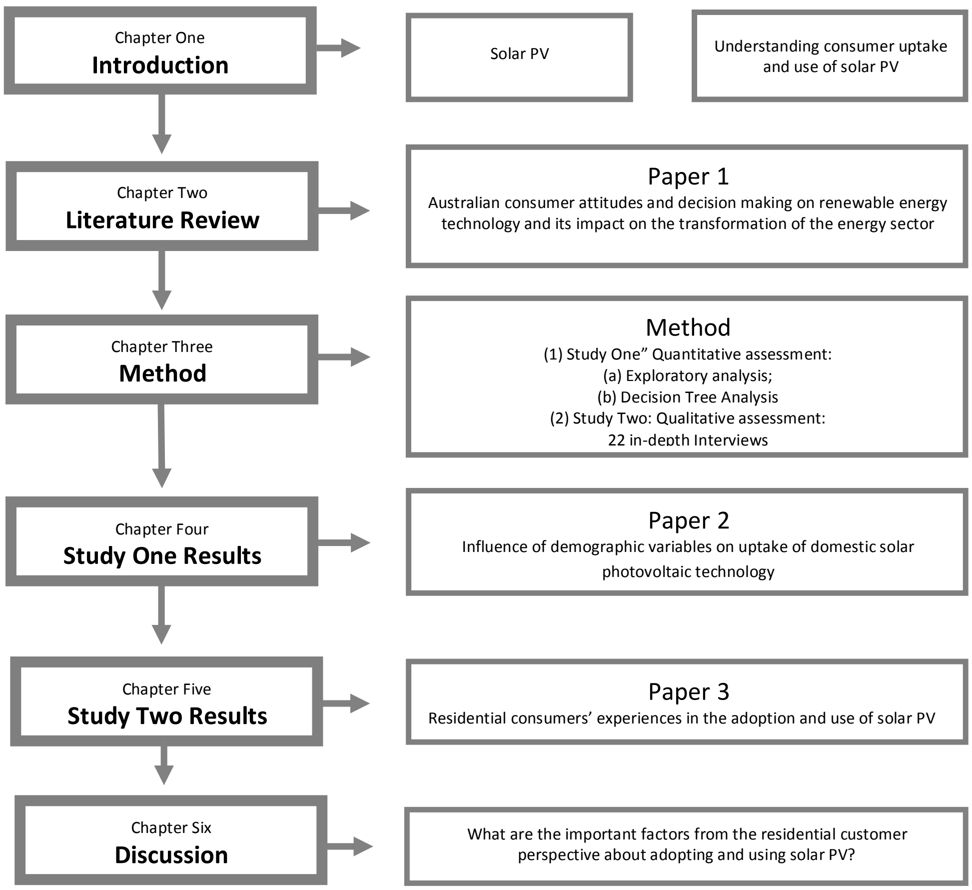

Figure 1.2 Relationship of thesis and chapters

The second section, Chapters Four and Five, report on the results of the two studies undertaken for this thesis that have been submitted for publication.

- Chapter Four reports on the quantitative review and reports on new knowledge ascertained from this study.
- Chapter Five reports on the results of a qualitative study of 22 persons across two cohorts and the new knowledge ascertained from this study.

The final section, Chapter Six, discusses the relationship between the chapters and demonstrates the logical link between the papers and how they form a coherent thesis. This section also details the strengths, weaknesses, opportunities, limitations, innovation and significance, and makes suggestions for further research.

Contributions of articles to objectives of this research project

Article One

The literature review undertaken for *Article One* critically examines current research on consumer attitudes and behaviour towards solar PV. This paper draws on a cross section of literature that reviews international and Australian research on consumer aspects of solar PV and its uptake. It identified that research into the consumer uptake of energy technology has been narrowly focused and this may limit the ability of policy makers to make informed decisions.

Article Two

This paper reports on a quantitative analysis of solar PV uptake in South East Queensland during the five years from 2010 to 2014. Using three different analytical methodologies, the importance of cross referencing different research methodologies to identify socio-economic variables, and how they may change over time and under different policy settings, is demonstrated. This paper makes a contribution to the field of energy policy by demonstrating the important inter-relationship between socio-economic variables and how they may influence the uptake of solar PV.

Article Three

Article Three reports on the lived experiences of 22 participants who acquired and used solar photovoltaic (PV), exploring their motivations to acquire solar PV and any subsequent changes in behaviour. Many of the examinations of solar PV policy have been whole-of-system reviews which often provide little insight into the motivations of consumers. Despite the awareness of the general importance of socio-economic variables that has arisen from these reviews of solar PV policy, there remains a knowledge gap about their individual and combined impact on the effectiveness of solar policies. This paper makes an in-depth examination of how people have used solar PV and looks at whether any resultant behavioural change provides insight into positive or adverse impacts on public policy outcomes. This paper makes a contribution to knowledge that would aid in the design of more effective and equitable renewable energy policies.

Summary

Previous research has investigated technical aspects of solar energy; however, there appears to be little research into the most recent surge in uptake of solar PV, which reflects an evolution in the adoption of this technology and a major transformation of the energy sector. There also appears to be less relevant research into the role of the domestic consumer who has been instrumental in this transformation. Policies that encourage the adoption of solar PV have a number of social, economic and environmental aspects and the role of the consumer is important in ensuring these policies are effectively targeted.

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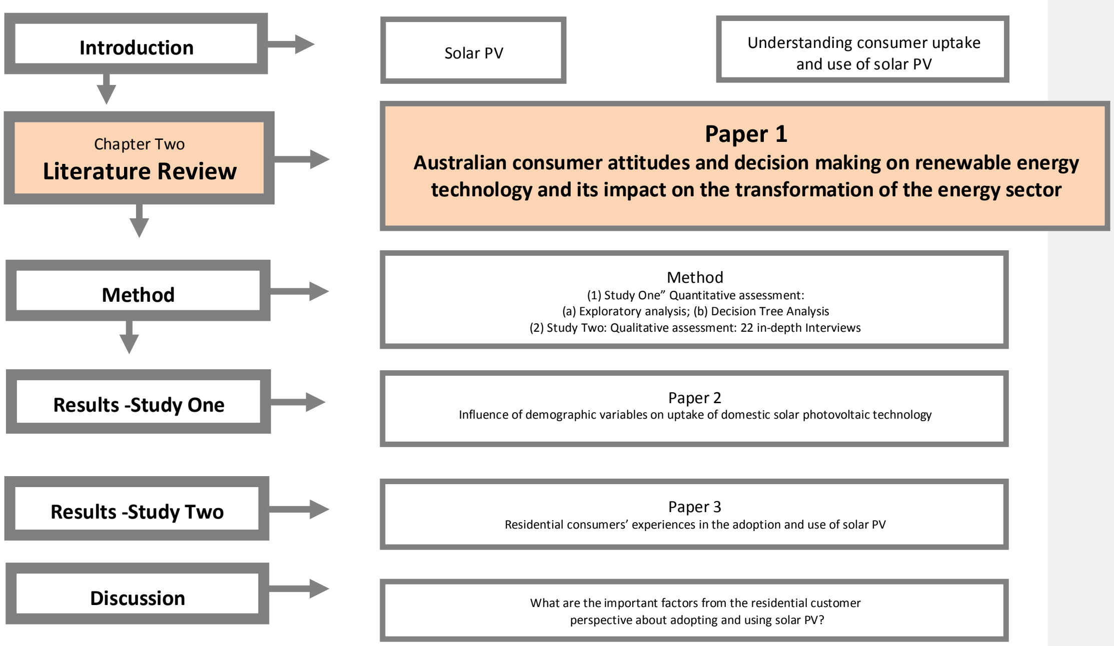
Chapter 2: Literature Review - Article One

2

This chapter is the first step in the exploration of consumer decisions about adopting and using solar PV. Article One critically examines research on consumer attitudes and behaviour towards solar photovoltaic (PV) and renewable energy technology in Australia. The uptake of renewable energy technology by residential consumers in Australia in the past decade has transformed the electricity supply and demand paradigm. This paper reviews Australian research on consumer behaviour, understanding and choices in order to identify gaps in knowledge.This chapter has been submitted to the Open Journal of Energy Efficiency. It was accepted on 16 September 2014 (Vol. 3, pp: 85-91). This chapter is presented here in the format submitted for that journal.

Figure 2.1 Relationship between this chapters and thesis



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The following is the suggested format for the required declaration provided at the start of any thesis chapter which includes a co-authored publication.

The authors listed below have certified that:
1. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit, and
5. they agree to the use of the publication in the student's thesis and its publication on the Australasian Research Online database consistent with any limitations set by publisher requirements.

In the case of this chapter:

Contributor	Statement of contribution
Jeff Sommerfeld	• Doctoral Student, School of Design, Queensland University of Technology (QUT) • Chief investigator, significant contribution to the planning of the study, literature review, data collection and analysis and writing of the manuscript.
Laurie Buys	• Professor, School of Design, Queensland University of Technology (QUT) • Significant contribution in the planning of the study (as associate supervisor) and assisted with data interpretation, preparation and evaluation of the manuscript.

Principal Supervisor Confirmation

I have sighted email or other correspondence from all Co-authors confirming their certifying authorship.

Professor Laurie Buys	QUT Verified Signature	
Name	Signature	30 August 2016

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Abstract

This paper critically examines research on consumer attitudes and behaviour towards solar photovoltaic (PV) and renewable energy technology in Australia. The uptake of renewable energy technology by residential consumers in Australia in the past decade has transformed the electricity supply and demand paradigm. Thus, this paper reviews Australian research on consumer behaviour, understanding and choices in order to identify gaps in knowledge. As the role of the consumer transforms there is a critical need to understand the ways consumers may respond to future energy policies to mitigate unforeseen negative social and economic consequence of programs designed to achieve positive environmental outcomes.

Key words

Solar Photovoltaic, Renewable Energy, Residential Consumers, Energy Policy, Australia, Transformation, Feed-in-Tariffs

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Introduction

In Australia, electricity generation is seen as key for high quality of life and economic development, yet it is responsible for 35 per cent of greenhouse gas (GHG) emissions (Evans, Strezov & Evans, 2010). For most of the past century, the dominant paradigm of the electricity demand and supply sector has been a technology-push versus consumer demand-pull which has defined traditional market participants (Taylor, 2008). The traditional linear dichotomy of the electricity sector has been rapidly transformed in the past decade, with a demand-pull by residential consumers seeking technological alternatives that supply more environmentally sustainable and cheaper electricity. Residential consumers who were once at the end of the energy supply chain are now using technology to transform themselves into producers and exporters of electricity.

As the role of the residential consumer transforms, there is a need to understand how the consumer will engage future energy policy in an era of technological change. Research into the uptake of energy technology has been identified as being narrowly focused and limited the ability of policy makers to make informed decisions to deal with the complexity of the modern electricity supply paradigm (Faiers et al., 2007). Recent transformation of the electricity sector has had negative social and economic consequence as a result of the implementation of policies designed to achieve positive environmental outcomes. An examination of accumulated Australian research, with supporting international knowledge on customer behaviour to solar and renewable energy technology is timely. The purpose of this article is to explore available Australian research on the energy behaviour, understanding and choices of residential consumers in order to identify gaps in knowledge that may guide future research specific to renewable energy and consumer engagement.

Background of Australia's electricity market

Historically, Australia's small population and vast expanses has been the driver for government initiation of key infrastructure. In late 19th century the electricity industry in Australia was based around numerous small utilities located in individual regional centres with the transfer to State ownership almost complete by the late 1940s. The National Electricity Market (NEM) that exists today did not evolve until the late 20th century (Quezada, Grozev, Seo & Wang, 2014). Currently, Australia's electricity network has more than $100 billion in assets with an electricity generation capacity of 54 gigawatts, more than 785,000 km of overhead transmission and distribution lines and more than 124,000 km of underground cables covering vast distance to serve a relatively small population of 23 million people (Kuwahata & Monroy, 2011).

Global economic and environmental policy shifts in the late 20th century have been the catalyst for change in the Australian electricity sector, including a move towards less government involvement, greater deregulated of energy markets and improved environmental outcomes (Quezada et al., 2014). The resultant policies led to greater emphasis on renewable energy and the emergence of solar as transformation technology. Government, business and individuals have become increasingly aware of the need to reduce our environmental impact and many individuals have moved beyond mere compliance by engaging in environmental friendly behaviours (Gadenne, Sharma, Kerr & Smith, 2011). Renewable sources of energy are viewed as the most economically viable and environmentally sound options to meet the growing energy needs of the world until technological and safety breakthroughs with other low emission technologies are achieved (Sener & Fthenakis, 2014). This has led to more than 100 countries implementing policies that provide support for renewable power generation and many of these include measures that support domestic solar PV (Oliva, MacGill & Passey, 2014). These economic and environmental policy changes have resulted in major electricity market upheaval and subsequent economic impacts with electricity prices increasing by more than 100 per cent in the past decade and contributing to the demand-pull for technology by consumers seeking alternatives to control costs.

Changing technology

The challenges for electricity markets internationally are significant with socio-economic changes and technological developments posing complex adaptation dilemmas for policy makers and utilities (Quezada et al., 2014). One of the most significant transformations, since

2001, has resulted from enhanced solar technologies and the domestic rooftop solar PV system. First patented in 1954 (Peters et al., 2012), the solar cell has in the past decade emerged as a major alternative source of electricity generation. Solar PV systems convert light energy directly into electricity by transferring sunlight photon energy into electrical energy, whereas solar hot water systems use solar radiation to heat water (Bahadori, 2013; Macintosh & Wilkinson, 2011). Consumer demand for solar and renewable energy and resultant government policies and incentives has given rise to almost 11 per cent of the Australia population (about 2.6 million people) now using solar for their electricity (Flannery & Sahajwalla, 2013).

Ongoing technological change such as battery storage is likely to further transform the energy demand and supply paradigm (Rudolf & Papastergiou, 2013). Transformational technology and the changing role of the consumer has the potential to impact traditional energy market participants which are likely to be faced with lessened demand for electricity from grids. Currently cost of infrastructure and electricity production is shared amongst all consumers. As customers reduce demand or opt out of the electricity supply system due to transformational technology, a diminishing number of customers will directly pay for the electricity supply system. Many of these customers are currently unable to access solar PV and renewable energy technology due to low income (affordability) or living arrangements (renting) (Byrnes et al., 2013; Grösche & Schröder, 2014). Upward pressure on electricity prices has the potential to migrate greater numbers of consumers to alternatives creating an exodus spiral from the traditional electricity market.

Socially, the move towards alternative energy sources has major ramifications for government policy, given the impact on consumers least able to afford new technologies such as solar PV and batteries. Customers from lower socio-economic demographics often spend a higher proportion of their income on energy and struggle to pay current electricity costs (Bahadori, 2013; Bell & Foster, 2013). The structure of incentives for uptake of solar PV technology such as Feed-in-Tariffs (FiTs) are mostly funded from higher electricity charges passed on to all customers (Grösche & Schröder, 2014). The policies that encourage consumer investment in solar PV and renewable energy technology also have an impact on the electricity network which was designed for a one-way flow of electricity but now must cater to domestic customers feeding solar electricity back into the grid.

The costs of these network upgrades supporting rooftop solar are paid for by all consumers further adding to the costs of people on lower incomes (Bahadori, 2013; Bell & Foster, 2013). In Australia and internationally socially regressive aspects of solar policies have resulted in the transfer of income from lower socio-economic groups to higher socio-economic groups. In many cases only higher socio-economic groups have possessed the necessary access to knowledge and capital that has enabled them to take advantage of solar programs (Byrnes et al., 2013; Nelson et al., 2012; Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011).

Australian solar and renewable energy programs

For 20 years, government policies have focused on reducing the cost of solar technologies for consumers and encouraging their uptake. These policies focused on several stages of the energy production chain including rebates for solar water heating systems and residential PV installations (Bahadori, 2013). The proportion of households with solar water heaters doubled between 1999 and 2011 (Ferrari, Guthrie, Ott & Thomson, 2012). In 2001, the Australian Government introduced the Mandatory Renewable Energy Target (MRET) scheme to encourage investment in renewable energy technologies (Ferrari et al., 2012). The scheme was split in 2010 into two parts: the Large-scale Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES). During this period the Australian Government provided rebates to householders who acquired solar PV systems called the Photovoltaic Rebate Program (PVRP) which was rebranded in 2007 as the Solar Homes and Communities Plan (SHCP) (Macintosh & Wilkinson, 2011). The SRES provided a fixed upfront incentive of about $5000 to reduce the capital cost of solar PV technology while most States and Territories offered the owners of small-scale solar PV installations a Feed-in-Tariff (FiT) that paid households for electricity generated (Nelson et al., 2012).

As a result of consumer demand and resultant government policies and incentives over one million rooftop solar PV systems have been installed in Australia. In just four years, between 2007 and 2011, the cumulative installed capacity of solar PV units increased 100-fold from about 10MW to more than 1000MW (Nelson et al., 2012). The state of Queensland, known as the “Sunshine State”, has the largest number of solar PV installations of any state, followed by New South Wales and Victoria (Flannery & Sahajwalla, 2013).

Consumer uptake of solar and renewable energy technology

For most of the past century the dominant paradigm of the electricity demand and supply sector has been a technology-push versus consumer demand-pull for this technology which has defined traditional market participants (Taylor, 2008). In recent years, better informed consumers are increasingly taking into consideration the environmental and social impact of products and services (Auger, Devinney, Louviere & Burke, 2010). As a consequence of consumer demand and resulting government policy there has been a demand-pull for better environmental, economic and social sustainability that has transformed the traditional linear dichotomy of the electricity sector. Consumers who were once at the end of the energy supply chain are now using technology to transform themselves into producers and exporters of electricity. Yet, much of the research to date has focused on either the reasons for adoption or non-adoption of renewable energy or the social consequences from it.

Prior to the surge in uptake in solar PV from 2008, Caird et al. (2008) undertook a study of consumers surveying reasons for adoption or non-adoption of renewable energy and energy efficiency measures. This research drew together previous quantitative surveys of consumers from the UK, USA and Australia on attitudes to renewable energy and installation barriers. The main drivers for installation were environmental concern and saving money whilst the main barriers were capital cost and lack of trustworthy information or reliable brands. It was concluded that research tended to focus on addressing financial, regulatory and information barriers and drivers. The researchers identified that social context was crucial in understanding consumer energy behaviour and sociological and anthropological research focusing on motivations and actions suggested consumer motivations were more complex.

Research focusing on the financial uptake of solar PV and renewable energy, examined the impact of policy mechanism used to encourage consumer uptake of solar PV such as the solar FiT (Byrnes et al., 2013; Nelson et al., 2012; Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011). An evaluation of the Australian Government Photovoltaic Rebate Program (PVRP), later rebranded the Solar Homes and Communities Plan, concluded the program was environmentally ineffective, economically costly and had social equity issues (Macintosh & Wilkinson, 2011). This Australian finding is similar to an examination of German climate policy that encouraged the uptake of solar PV and use of FiT's (Grösche & Schröder, 2014). In the decade between 2000 and 2011 the share of renewables in Germany increased from seven to 20 per cent. Whilst FiT policies in Germany encouraged the dissemination of renewables technology, subsidies that unpinned the expansion increased from 900 million Euros to 16.7 billion Euros that was funded by adding three Euro cents per kilowatt hour to the cost of bills. The authors concluded these policies were regressive as they facilitated that expansion of expensive technology without fostering cost-reducing innovation and had a negligible impact on climate protect (Grösche & Schröder, 2014).

Social context to customer decisions to adopt or non-adopt solar PV and renewable energy technology appears to have so far attracted limited research interest to date. Hampton and Eckermann (2013) explored the ways social learning can be used to improve understanding of solar PV's based on changing attitudes. Through qualitative workshops in 2005 and 2012, knowledge and understanding of solar PV and renewable energy products was found to have considerably improved during the two workshops but customers still had difficulties understanding financial aspects of solar PV policy.

The profile of consumers adopting renewable energy technologies appears to be inconclusive with investigations into educational status and environmental behaviour providing conflicting evidence. Demographic variables associated with positive environmental attitudes such as age, gender and income have identified conflicting conclusions (Faiers et al., 2007). For example, the researchers identified studies that found having a higher education level encouraged environmentally positive behaviour whilst another study found less educated consumers were more likely to be green consumers. To overcome demographic variations a study of Australian consumers cross referenced both socio-economic status based on income and value of the housing (Nelson et al., 2011). They found that lower income households were not engaging solar PV and renewable energy technology and property ownership was the most important criteria in decisions to adopt or non-adopt solar PV and renewable energy technology.

Impacts of consumer uptake of solar and renewable energy technology

Whilst consumers may have been mentioned in most research, the majority of researchers focused on energy policy at the national and international level with specific attention on government energy policies and the implications of these policies. Solar PV has diverse economic, environmental and social values and policies encouraging it has generally been developed and implemented without any comprehensive social cost-benefit analysis being undertaken (Oliva et al., 2014). The research examining consumer uptake of energy technology focused on addressing financial, regulatory and information barriers and drivers. Underpinning much of the research is a primary assumption that environmental outcomes are the key indicator of success. This type of examination looked at societal values from solar PV including carbon abatement, consumer outcomes from deferring network augmentation and offsetting energy losses (Oliva et al., 2014; Timilsina, Kurdgelashvili & Narbel, 2012; Solangi, Islam, Saidur, Rahim, & Fayaz, 2011; Zahedi, 2010). Evaluations of the policies that encourage the uptake of renewable technology found that only some home owners had the capacity to afford and install solar PV systems based on socio-economic profiles (Byrnes et al., 2013; Nelson et al., 2012; Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011). In examining the uptake of solar energy policies, the type of housing was identified as an obstacle (e.g. apartment, unit) or living arrangements (e.g. renting) (Byrnes et al., 2013). Overall the policies that encouraged renewables also were found to impose additional networks costs that were funded by consumers not using renewables. These customers were further disadvantaged if they were on lower incomes as they spend a higher proportion of their income on energy (Bahadori, 2013; Bell & Foster, 2013).

In an examination of government policies that encouraged the technological transformation, Taylor (2008) concluded the effectiveness of innovation was not a primary consideration. Immediate pollution reduction and energy conservation has been the policy drivers rather than an empirical evaluation of the comparative effects of various options. Additionally, research into the uptake of solar and renewable energy technology by consumers is mostly silent on the impact of renewable energy uptake on other consumers. The unforeseen outcome of consumer decisions to adopt or not adopt solar and renewable energy technology has been an increase in the social divide between consumers (Bell & Foster, 2013; Byrnes et al., 2013; Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011).

Conclusion

Currently the research focus is on single aspects of environmental, economic or social attitudes of consumers and the impact on the electricity sector or electricity policy (Bahadori, 2013; Auger, 2010; Martin & Rice, 2010). Other researchers tended to focus on policy, policy-induced technical change, financial issues and consumer environmental attitudes (Negro et al., 2012; Peters et al., 2012; Gadenne et al., 2011). Policy and policy implications were explored, but the investigations did not extend to examining the consumer behaviour resulting from these policies. Whilst the phenomena relating to consumer energy was a key research focus, researchers did not explain the motivation or context of consumers who adopted or did not adopt renewables technology. As a result much of the research is inconclusive with regards to understanding consumer behaviour.

Consumers were examined from a macro perspective rather than the more complex approach recommended by Caird et al (2008) and Faiers et al (2007). Conclusions on the effectiveness of solar and renewable energy technology policy needs to address the complex social, economic and environmental interactions and outcomes that lead to a holistic understanding and insight into the complexity of energy use and impact. Research needs to address this complexity in order to identify and integrate the social, technical and environmental changes and their impact on the diverse groups of consumers.

Internationally, a review of the European *Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe* (REMODECE) project identified the importance of ongoing research to track the influence of trends in technology and consumer behaviour. The REMODECE project was established to better understand household energy consumption and identify demand trends. It found research examining consumer uptake of energy technology must encompass personal values and attitudes and the impact of external factors (de Almeida et al., 2011). Research needs to go beyond cognitive assessment and rational choice because emotional, societal and cultural issues impact on consumer energy behaviour (Faiers et al., 2007).

In conclusion, the purpose of this paper was to examine contemporary research on consumer behaviour, understanding and choices towards solar technology in Australia. With almost 11 per cent of the Australian population are now using solar for their electricity, research in this area is essential to developing future policy. The rapid uptake of technology by consumers has not only transformed the demand and supply dichotomy but also social and economic aspects of the electricity market. The consumer decision to acquire a solar PV system is complex requiring information that most average consumers are unlikely to have in early stages of new technology (Guidolin & Mortarino, 2009). Research into the consumer uptake of energy technology has been narrowly focused and limits the ability of policy makers to make informed decisions (Caird et al., 2008). Understanding the demand-pull social phenomena has significant relevance given the equity issues for low-income consumers. Whilst the adoption of solar PV is positive in terms of environmental concerns, researchers have failed to adequately examine the resultant economic or social consequences across user groups. As the role of the consumer transforms, there is a need to understand how the consumer will engage future energy policy to mitigate unforeseen negative social and economic consequence of programs designed to achieve positive environmental outcomes.

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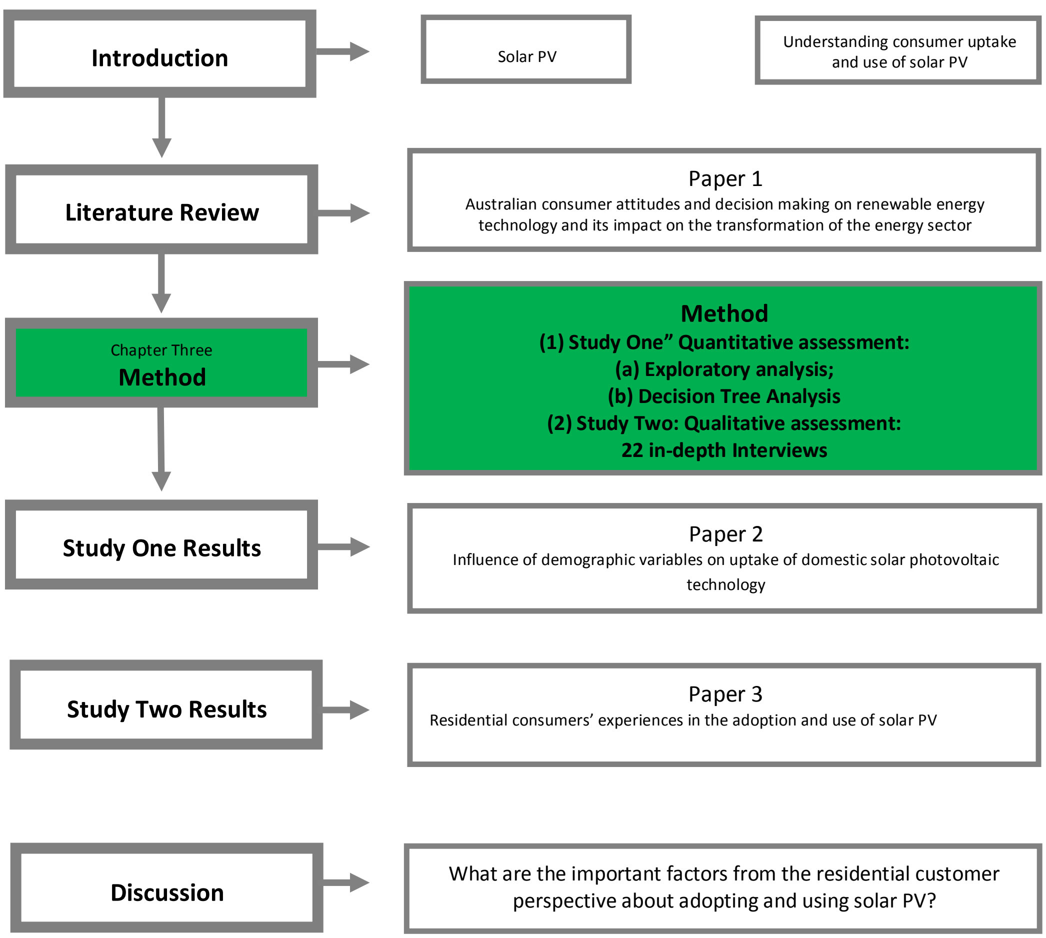
Chapter 3: Method

3

This chapter outlines the methods used to explore consumer decisions about adopting and using solar PV.

Figure 3.1 Relationship between this chapters and thesis



Overview

> The history of science is replete with examples of qualitative inquiry conducted in conjunction with, and independent of, quantitative inquiry (Fisher & Stenner, 2011).

The research for this thesis took a multi-method research approach, which involves the integration of quantitative and qualitative methods in a single study for the purposes of obtaining a fuller picture and deeper understanding of a phenomenon (Johnson, 2007). The recent history of mixed research in the social, behavioral and human sciences started with researchers who believed both qualitative *and* quantitative methods were useful in addressing their research questions (Johnson et al., 2007). Mixed method researchers argue that mixing methods and including some quantitative evidence in a qualitative research design can indeed strengthen sociological explanation (Spillman, 2014).

A mixed methods study involves the collection of both quantitative and qualitative data in a single study, in which the data are collected concurrently or sequentially, with the integration of the data at one or more stages in the process of research (Tashakkori & Teddlie, 2003). The benefit of the mixed method is that it allows the researcher to weigh the different methods, and alleviates perceptions of focusing solely on the numeric information of some quantitative methodologies that may miss the depth and details that can come from qualitative research (Wheeldon & Ahlberg, 2012). Another benefit is it provides research from multiple perspectives rather than from a single perspective, allowing *triangulation of measure* by taking multiple measures of the same phenomena (Neuman, 2011).

In social science, Campbell and Fiske's (1959) article is viewed as formalising the practice of using multiple research methods (Johnson et al., 2007). The multi-method approach depends upon four (4) factors:

1. Theoretical perspective - based either directly or indirectly on a theory;
2. Priority of strategy - the balance of qualitative and quantitative
3. Sequence of data collection, and;
4. The point at which the data are integrated (Terrell, 2012).

A review published in the early 2000s identified about 40 different mixed method research designs. Of these, six are most often used, including three concurrent and three sequential designs (Ivankova, Creswell & Stick, 2006). One of those designs is the mixed-methods sequential explanatory strategy (Terrell, 2012), where unknown variables can be identified and propositions tested (Blaikie, 2010). This strategy is based on the collection and analysis of quantitative data followed by the collection and analysis of qualitative data. It requires a researcher to consider methodological issues such as:

- the weight given to the quantitative and qualitative data collection and analysis in the study;
- the sequence of the data collection and analysis;
- the stage/stages in the research process at which the quantitative and qualitative phases are connected; and
- how the results are integrated (Ivankova et al., 2006).

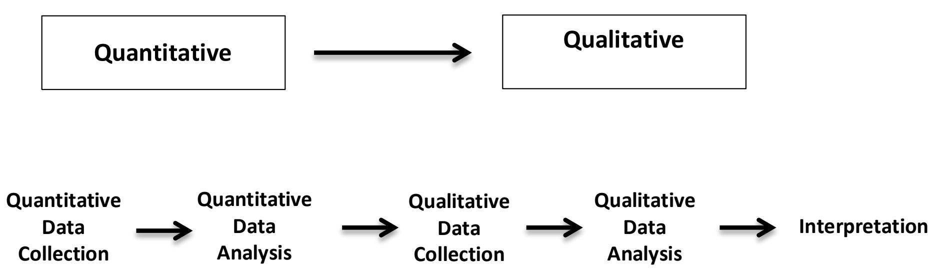


Figure 3.2: Sequential explanatory strategy (Terrell, 2012)

The research used in this project has multiple stages, each of which follow dedicated methodology concerning the use of various research methods. The phases for this project are:

1. Literature review undertaken in a systematic way
2. Quantitative analysis using an event history format based on multi-sourced secondary data
3. Qualitative research using in-depth semi-structured face-to-face interviews
4. Synthesis of literature, quantitative analysis and qualitative research

Research Approach

The philosophical perspective for the research approach for this thesis is based on an interpretivist phenomenological ontology. Such an ontology acknowledges that a researcher may have some prior insight into a topic, but that he or she wants to gain an in-depth knowledge of motivations and behaviour through the study of the lived experiences of ordinary people (Crotty, 1998; Denzin & Lincoln, 2000; Neumann, 2011). The interpretivist component of the ontology or epistemology adopts the approach that the knowledge is socially constructed based on the actions of people in everyday situations rather than being objectively determined (Lincoln & Guba, 1985; Neumann, 2011). Completing this epistemology is a phenomenological ontology which is a descriptive study of how individuals experience a phenomenon (Baker, 1994; Neumann, 2011). The phenomenological approach allows researchers to illuminate important aspects of the lived experience from the perspective of the individual enabling the researcher to better appreciate the phenomena, thus further enhancing and enriching the interpretivist component of the ontology.

While this research is socially constructed based on how people adopt and use solar PV in everyday situations rather than objectively determined, it begins with the acknowledgement that there is a gap in our understanding of residential consumers' acquisition and use of solar PVs under different policy settings, which has not been overtly described and explained previously. The research examining this knowledge gap is based on the mixed method approach using a quantitative (Study One) and qualitative (Study Two) analysis of consumers and their acquisition and use of solar PV. Mixed method researchers argue that the ontological divide between qualitative and quantitative methods is unnecessary and counterproductive as mixed method research enables the confirmation of each method through triangulation (Fisher & Stenner, 2011; Spillman, 2014).

Study One

This study utilised existing multi-source quantitative secondary data to develop profiles in relation to the uptake of solar PV programs to ascertain the significance of any differentiation.

The data for this research used information on the uptake of solar programs since 2008 as the explanatory variable for a quantitative analysis, and matched this with selected demographic variables. The analysis of this data was based on the processes used in an event history analysis (EHA) (Berry & Berry, 1990), which can be applied to longitudinal data to analyse change or an event. The quantitative analysis for this project was based on annual intervals from July 2010 to July 2014, in which the explanatory variable (solar PV) was compared to selected demographic explanatory variables to identify significant influences.

For this study, solar PV programs were selected because of the significant uptake by consumers with almost 11 per cent of our population now using this technology for their electricity needs. Data for solar energy programs that has been collected for more than a decade, was based on the annual uptake of solar energy programs. Within Australia, the state of Queensland has the largest number of solar photovoltaic installations of any state, with almost one-half of the population of Queensland concentrated in the Greater Brisbane area.

The Greater Brisbane area is sub-divided into 115 postal areas (postcodes); this method of division is used by multiple agencies for data collection and allows for data comparison. The postcode-based data is publicly available and the postal code scale is large enough to ensure individual consumers cannot be identified.

Table 3.1: Explanatory variables

Socio-economic variables	Definition (ABS)
People	Total number of persons in the postal area
Families	Two or more persons, one of whom is at least 15 years of age, who are related by blood, marriage (registered or de facto), adoption, step or fostering, and who are usually resident in the same household.
Income	Gross income from all sources
Education	Number of persons with a university or tertiary qualification
Over 55 years	Persons aged over 55 years old
Over 65 years	Persons aged over 65 years
Owners	Own a dwelling outright or with a mortgage
Renters	Renting a dwelling
Mortgage	Housing loan repayments being paid on a monthly basis by a household to purchase the dwelling
Rent	Dollar amount of rent paid by households on a weekly basis for the dwelling
Private homes	Number of all private dwellings
Houses	House which stands alone in its own grounds separated from other dwellings by at least half a metre
Units	Includes flats, units and apartments - dwellings that do not have their own private grounds and usually share a common entrance foyer or stairwell
Duplexes	Semi-detached dwelling including terrace house and townhouses - dwellings that have their own private grounds and no other dwelling above or below them
Three bedrooms or more	Occupied private dwellings with three or more bedrooms

Source: ABS Census Directory http://www.abs.gov.au/ausstats/abs@.nsf/0/4B6D4A6E729E8275CA25720900078321?opendocument
Accessed 13 March 2015

The demographic data for this research was obtained from the Australian Bureau of Statistics (ABS) from the 2011 Census (ABS, 2013). Table 3.1 shows the selected demographic information used for this study, which includes median weekly income; median mortgage payments; median weekly rent; population; dwelling type; ownership status; number of bedrooms and education status (university or tertiary). Data on solar installation was obtained from the Australian Government Clean Energy Regulator (AGCER, 2014) and local electricity distributor Energex, which was then allocated to postal areas using postcode information from the ABS. The AGCER data accumulated solar installations annually over a period of 12 years from 2001 to 2012. The Energex data provided information for the 117 postal areas from 2008 to 2014, which could be cross-validated with the AGCER data.

Exploratory analysis

The preliminary exploratory analysis involved the extraction of stratified sets of postcodes from the census data for each demographic variable of interest, and construction of tables with corresponding annual solar PV uptake figures. The stratified sets comprised 15 postcodes with the five largest, five middle and five smallest values of the respective variable; the middle values were those spanning the median. These summary statistics were then examined for consistency of trends and compared with previous policy analysis and socio-economic conclusions on uptake of solar PV. Previous research on the factors that influenced uptake of solar PV have asserted financial capacity as an important factor in solar PV uptake (Byrnes et al., 2013; Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011; Nelson et al., 2012).

Table 3.2: Exploratory Analysis – Solar installations and Median Weekly Income

	Rank	Postcode	Median weekly income	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4069	$2,347	3.26%	6.58%	13.10%	19.68%	22.70%
	2	4065	$2,286	2.51%	4.41%	8.15%	12.87%	14.63%
	3	4156	$2,265	4.11%	8.54%	16.97%	29.82%	35.62%
	4	4154	$2,261	2.58%	6.95%	15.76%	26.59%	31.78%
	5	4155	$2,230	6.29%	10.57%	22.00%	37.14%	43.43%
Middle	55	4165	$1,478	5.06%	11.08%	19.46%	28.17%	32.36%
	56	4101	$1,475	1.27%	2.13%	3.83%	5.65%	6.25%
	57	4173	$1,474	2.98%	6.91%	13.95%	20.39%	23.88%
	58	4179	$1,465	4.07%	7.35%	13.78%	19.81%	22.38%
	59	4159	$1,462	5.65%	10.95%	19.44%	28.03%	31.97%
Bottom	113	4303	$855	1.88%	4.91%	10.48%	14.45%	16.47%
	114	4205	$848	3.90%	10.47%	22.27%	27.55%	31.40%
	115	4183	$801	2.04%	5.34%	9.43%	14.37%	15.90%
	116	4507	$747	4.34%	12.42%	21.01%	27.36%	30.34%
	117	4184	$598	7.88%	13.34%	19.54%	25.11%	27.52%

The exploratory analysis used five different demographic explanatory variables to examine the influence of financial capacity and solar PV uptake; an example of this is shown in Table 3.2. (All tables from this study are at Appendix B)

Decision tree analysis

The results from the exploratory analysis identified similarities, differences and gaps in the findings of previous literature, and further quantitative analysis was undertaken. This *triangulation of measure* (Neuman, 2011) within the quantitative study allowed for multiple measures of the same phenomena using different quantitative measurements. The second analysis of the full dataset, comprising the selected demographic variables and annual uptake data, was analysed using two types of decision trees: classification and regression trees (CART) and boosted regression trees (BRT). The aim was to provide a simple-to-understand representation of the nuanced relationship between the set of demographic factors (explanatory variables) and the probability of an individual taking up solar PV (the response variable).

The analysis software was obtained via the RPART and GBM packages, which are widely used for statistical analysis, classification and clustering (http://www.r-project.org/). Decision trees are general purpose prediction and classification mechanisms that are used in a range of data mining and knowledge discovery (de Ville, 2013). These models provide a simple-to-understand representation of the relationship between a response variable (solar PV) and potential explanatory variables, and are accepted in many fields of research because they can identify and interpret complex hierarchical relationships (Hu, O'Leary, Mengersen & Choy, 2011).

Decision tree models aim to segment the data into a set of subgroups, where the responses within each subgroup are similar. The subgroups are formed by selecting a set of variables and a series of binary splits of these variables, until a specified stopping rule is reached. In the current study, subgroups of postal areas are created based on similar percentages of uptake of solar PV. The method first determines the variable and the splitting point that provides the best division of postal areas into two groups (higher and lower solar PV uptake), then within each group it identifies the next variable that splits into two subgroups, and so on until the stopping rule is reached. The result is usually depicted as a tree-like structure with the splitting variables as nodes in the tree, the binary splits as branches of the tree, and the subgroups of postal PVs as the terminal nodes. In the current study, the model provided the average solar PV uptake per person in the postal PVs in each of the terminal subgroups.

Two types of trees were used in this research. The first type is a classification and regression tree (CART) that is a flowchart-like structure with branches that represent a split in the dataset based on the displayed decision rule, and final nodes showing the characteristics of the corresponding subset of observations (Figure 3.3).

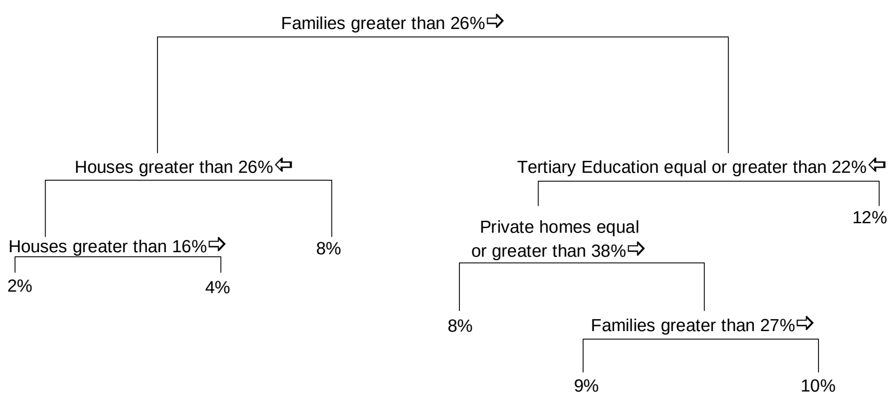


Figure 3.3: Classification and regression tree for 2014 using R software

The second type is a boosted regression tree (BRT), which shows the relative influence of the demographic variables (Figure 3.4). Decision trees represent information in a way that is simple to interpret and easy to visualise, with predictor variables able to be of any type and scale of measurement (McCluskey, Dzurllkanian & Norhaya, 2014).

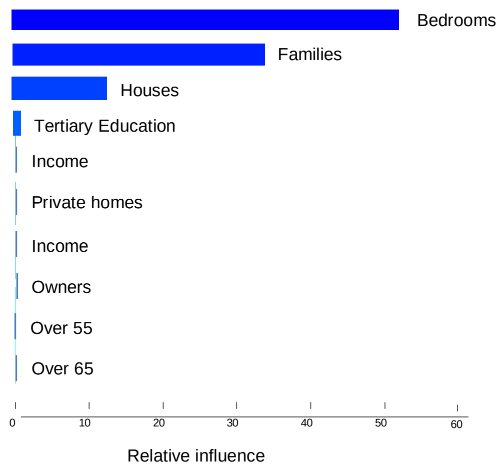


Figure 3.4: Boosted regression tree for 2014 using R software

The CART and BRT decision trees provide complementary information. The CART is a single decision tree based on the full dataset and shows the set of most influential explanatory variables. The BRT constructs many small trees based on subsets of the data and shows the relative influence of the variables. It should be noted that decision trees do not provide a p-value as in traditional linear regression, but instead provide a measure of the relative importance of the variables in the model. The overall fit of the decision tree model is optimised by multiple-fold cross-validation.

The synthesis of the quantitative analysis was undertaken to triangulate the different qualitative methods using an exploratory factor analysis, which is a process of creating groups of variables that have high correlations with other groups of variables (Tashakkori & Teddlie, 2003). An exploratory factor analysis assesses:

- convergent validity (high correlation with each explanatory variable); and
- discriminant validity (low correlation with each explanatory variable) (Neuman, 2011).

Study Two

The next stage of the project was designed as a qualitative explorative field study using semi-structured in-depth interviews (Neuman, 2011). This research took a qualitative phenomenological approach, which gives priority to participants' own words and voices in expressing and understanding their day-to-day lived experiences. Phenomenological research is a descriptive study of how individuals experience a phenomenon. It begins with the acknowledgement that there is a gap in our understanding of a specific phenomenon, which has not been overtly described and explained. Phenomenological researchers hope to gain an understanding of the essential 'truth' of the lived experience from the perspective of the individual (Baker, 1999; Crotty, 1998; Denzin & Lincoln, 2000; Neumann, 2011). This approach allows a researcher to "understand" the real life experience of the participants, and the phenomena of residential electricity use behaviour change. Qualitative research is particularly appropriate for obtaining in-depth insight into issues and topics for which little knowledge exists, especially when a primary research goal is to understand how social and cultural contexts affect processes, decisions and events. It is important to acknowledge how philosophical assumptions, world views and researcher's beliefs and attitudes are interconnected and influence how researchers engage with, study, approach and understand qualitative case study research. This method for this study acknowledges it consist of a stance towards the nature of reality (ontology), how the researcher knows what she/he knows (epistemology), the role of values in the research (axiology), the language of research (rhetoric) and the methods used in the process (methodology) (Creswell, 2003).

Qualitative research is a social research method used to gain in-depth knowledge and understanding of a particular issue or question. The purpose is to collect data that illuminates the richness and complexity of phenomena that would not be achieved using a quantitative approach (Morris et al, 2014). Interviews used in social science methodology allow the researcher to engage in a conversation with participants to explore their subjective opinion about a technology, its usefulness, and barriers to use (Connelly et al, 2014). Unlike quantitative research, in qualitative research, sample size is less important, with the importance on the patterns and themes that accurately represent meaning.

In this second qualitative study, 22 participants were drawn from the same geographic region used for study one. Two cohorts of consumers were identified, allowing qualitative data to be organised in a chronological sequence called an *event structure analysis*, which is used to create a narrative that can facilitate observation of casual relationships (Neuman, 2011). The benefit of this approach is that it is similar to the approach taken for the quantitative analysis based on an EHA and can be the basis for testing reliability and validity of the research. Reliability is concerned with the consistency of results over time, whereas validity considers the design methods and measures in the investigating of the broader issues (Wheeldon & Ahlberg, 2012).

The qualitative interviews were carried out in 2015. Criteria for inclusion were based on the person having acquired a domestic rooftop solar PV system and being the principal decision maker for its acquisition. The age of participants was not a criterion, although ethical clearance for the research required that participants be aged over 18 years. Two cohorts of participants were identified for interview: those persons who acquired domestic rooftop solar PV during the period from 2008 to July 2012 at which time a solar FiT of $0.44 was payable; and those persons who acquired domestic rooftop solar PV after July 2012, at which time a solar FiT of $0.06 was payable. The age of participants was irrelevant in selection for interview. In the case of households with more than one occupant, the criterion for interview was the occupant who was the principal decision maker for acquiring solar PV.

Ethics

Ethical approval for this project was obtained from the Queensland University of Technology University Human Research Ethics Committee (UHREC). Standard good practice ethical protocols were followed and written consent was obtained from each participant. The participants were recruited using existing networks from within and outside the University. For example, an email outlining the project was sent to university and social networks. The email asked recipients to consider whether they would be eligible or whether they were aware of other persons who would meet the criteria for the research. Participants who were likely to meet these criteria were then contacted in person and provided with an Information Sheet (Appendix C) that outlined: the details of the research; the benefits and risks associated with participating; and the measures undertaken to ensure anonymity was protected. Participants were then contacted to arrange an appointment for an in-depth semi-structured interview in their homes. Prior to commencement of interviews, participants were once again provided with documents about the research and written consent was obtained. Interviews lasted from 45 to 60 minutes and these were electronically recorded.

Participants

Of the 22 participants interviewed (to date) for this study, 12 persons acquired solar PV during the period from 2008 to July 2012 when FiTs were $0.44 (Table 3.3). The remaining 10 participants acquired solar PV after July 2012 when FiTs were reduced to the current $0.06 (Table 3.4).

Table 3.3: Solar Interview Participants - $0.44 Feed-in Tariff

Interview	Age	Gender	Dwelling	Occupants	Years in home	Income	Education	Occupation
01	58	F	House	2	35	<$70k	PhD	Education
02	60	M	House	2	10	>$90k	Senior	Government
03	53	M	House	4	10	>$90k	PhD	Science
04	34	M	House	2	8	>$90k	Tertiary	Professional
05	88	F	Townhouse	1	15	<$30k	Primary	Retired
06	46	M	House	4	10	>$90k	PhD	Education
07	84	F	Townhouse	1	7	<$50k	Senior	Retired
08	81	F	Townhouse	1	22	<$30k	Primary	Retired
09	79	M	House	2	20	<$50k	Primary	Retired
10	68	F	House	1	4	<$30k	Tertiary	Retired
11	57	M	Townhouse	2	17	>$90k	PhD	Education
12	83	M	House	1	49	<$30k	Primary	Retired

Table 3.4: Solar Interview Participants - $0.06 Feed-in Tariff

Interview	Age	Gender	Dwelling	Occupants	Years in home	Income	Education	Occupation
01	60	F	House	3	3	>$90k	Tertiary	Health
02	53	M	House	2	2	<$70k	Tertiary	Professional
03	62	M	House	2	12	<$70k	Senior	Retired
04	53	F	House	2	5	>$90k	Senior	Travel
05	63	M	House	2	15	>$90k	Tertiary	Self-employed
06	44	M	House	2	2	<$70k	Tertiary	Professional
07	33	F	House	5	6	>$90k	Tertiary	Education
08	62	F	House	2	11	<$70k	Tertiary	Retired
09	68	M	House	2	11	<$70k	Secondary	Self-employed
10	35	M	House	4	9	>$70k	Secondary	Trade

Data Collection

The first section of the interview was a general discussion about the participant's decision making when acquiring goods or services. The purpose of this was to elicit triple-bottom-line (TBL -social, economic, environment) views of each participant as part of decision making for the purchase of goods and services. Interviews were open-ended and semi-structured and participants were asked what important considerations they used when making purchasing decisions. The type of typical questions asked were: "When you are choosing a product of service, what are the features that you consider most important?"; "What things do you look for, when you are purchasing a product?" Prompts included what they looked for in products such as white goods or motor vehicles. The type of prompts included: "If you were going to go and buy a new fridge today, what would be the features you would look for?" Additional prompts included asking what they looked for in day-to-day products such as groceries. Additional prompts included questions that asked for specific TBL responses with questions such as: "When you are looking at a product, do you ever consider its environmental impact?; "When you are looking at a product , do you consider things like social aspects of it, such as where it's manufactured?"

The second part of the interview was a discussion on what were the issues that led them to acquire solar PVs; the acquisition process; and the results of the acquisition. Participants were asked: what motivated them to acquire solar PV; the information they relied upon to make this decision; their confidence and trust in the information; and whether the acquisition of solar PV resulted in any behavioral change. Typical questions included: "What motivated you to get a solar unit?; When you went to go and buy it, where did you get your information from?; Did you change behaviour?" At the conclusion, a brief demographic survey was undertaken to obtain key socio-economic information.

Analysis

A phenomenological approach was taken in conducting this research, in order to gain insight into the real life experience of participants and to explore their perceptions through interview questions and answers (Gomm, 2004). The interviews were audio-recorded and transcribed verbatim. The data were explored and coded manually after the transcripts were read and re-read to identify common and contrasting concepts. Thematic analysis involves a process of data immersion and interpretation, meaning transcripts are read and re-read and then coded into common categories, themes and patterns (Wrapson et al, 2014). The data was manually coded into categories and concepts that emerged from the data. These themes and sub-themes were grouped and labelled, based on a triple bottom line (TBL) approach to enable the creation of a comprehensive picture of the pre- and post-solar PV motivations and behaviour of participants. Critically, these have been summarised in tables reflecting each cohort that give insight into this thematic structures, as the results reference multiple excerpts from the raw data. These tables allowed the anonymity of participants to be protected through the use of a numeric identifier that summarised the demographic details of the participant in a non-identifiable format.

Conclusion

A major strength of this thesis is that it uses two different studies and mixed methods to address the research question relating to how residential customers make decisions about adopting and using solar PV. The quantitative and qualitative findings that emerged from the two studies were then integrated to identify factors associated with acquiring solar PV and how this acquisition may provide a better understanding of energy use behaviour under different policy settings. These methods provide a means to better understand the lived experiences of people and the inter-relations with public policy under different settings.

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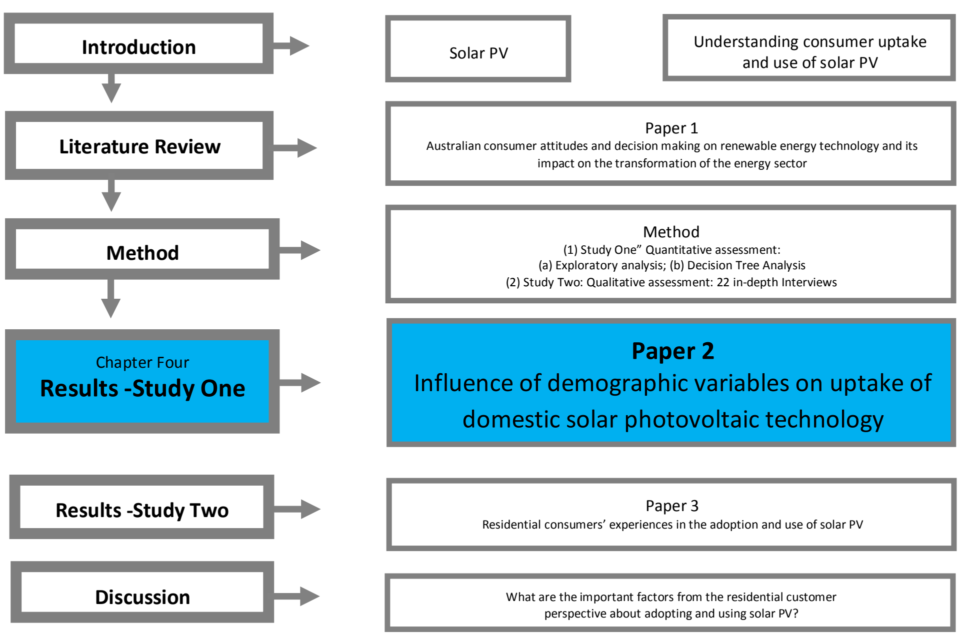
4

Chapter 4: Paper 2 – Quantitative Assessment

This paper reports on a quantitative analysis of solar PV uptake in South East Queensland during the five years from 2010 to 2014. Utilising three different analytical methodologies, this research methodology demonstrated the importance of cross referencing different research methodologies to identify socio-economic variables and how they may change over time and under different policy settings. This paper makes a contribution to the field of energy policy by reviewing a range of external factors that influence decision making of consumers in the uptake of energy technology and also by highlighting some of the negative consequences including equity issues that need to be mitigated with such policies.This chapter has been submitted to Renewable & Sustainable Energy Reviews and is presented here in the format submitted for that journal.

Figure 4.1 Relationship between this chapters and thesis



Statement of Contribution of Co-Authors for Thesis by Published Paper

Publication title: Influence of demographic variables on uptake of domestic solar photovoltaic technology

Journal Submitted to: *Renewable & Sustainable Energy Reviews*
Impact Factor: 5.510 (revised and under review)

The following is the suggested format for the required declaration provided at the start of any thesis chapter which includes a co-authored publication.

The authors listed below have certified that:

1. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

3. there are no other authors of the publication according to these criteria;

4. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit, and

5. they agree to the use of the publication in the student's thesis and its publication on the Australasian Research Online database consistent with any limitations set by publisher requirements.

In the case of this chapter:

Contributor	Statement of contribution
Jeff Sommerfeld	Doctoral Student, School of Design, Queensland University of Technology (QUT) Chief investigator, significant contribution to the planning of the study, literature review, data collection and analysis and writing of the manuscript.
Laurie Buys	Professor, School of Design, Queensland University of Technology (QUT) Significant contribution in the planning of the study (as associate supervisor) and assisted with data interpretation, preparation and evaluation of the manuscript.
Kerrie Mengersen	Professor, Science and Engineering Faculty, University of Technology (QUT) Significant contribution in the planning of the study (as associate supervisor) and assisted with data interpretation, preparation and evaluation of the manuscript.
Desley Vine	Research Fellow, School of Design, Queensland University of Technology (QUT) Significant contribution in the planning of the study (as associate supervisor) and assisted with data interpretation, preparation and evaluation of the manuscript.

Principal Supervisor Confirmation

I have sighted email or other correspondence from all Co-authors confirming their certifying authorship.

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Influence of demographic variables on uptake of domestic solar photovoltaic technology

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Abstract:

In Australia during the past decade there has been a significant transformation of the electricity demand and supply sector. In five years from 2008 to 2013 the number of Australians installing solar photovoltaic (PV) technology grew from 8000 to more than one million. Governments in Australia used a range of policy incentives such as feed-in tariffs (FiTs) to encourage the uptake of solar PV and this had a range of consequences. From a dynamic perspective, solar technology has transformed the residential consumer electricity market providing some consumers with greater choice in demand and supply of their power. However, for other consumers it has resulted in energy poverty and greater pressure on government and regulators to control spiralling electricity prices. An exploratory review of data covering almost 2 million people in south east Queensland found inconsistencies and gaps in previous research findings. Utilising three different analytical methodologies, this research examined the demographic data to ascertain the relative influence and significant of key variables on household uptake of solar PV technology. Based on a comparison of the three methods, a more nuanced explanation of the

socio-economic variable influencing solar PV uptake is offered which could be used to shape future FiT policies.

Key words: domestic consumers, consumer change, solar photovoltaic (PV), demographic variables, feed-in tariff (FiT)

Abbreviations: Australian Bureau of Statistics (ABS); boosted regression trees (BRT); classification and regression tree (CART); feed-in tariff (FiT); greenhouse gas (GHG); Mandatory Renewable Energy Target (MRET); photovoltaic (PV); Photovoltaic Rebate Program (PVRP); Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe (REMODECE)

Introduction

For most of the past century the dominant paradigm of the electricity demand and supply sector has been a technology-push versus consumer demand-pull which has defined traditional electricity market participants (Taylor, 2008). However, in recent years a demand-pull for greater environmental, economic and social sustainability from government and the electricity sector has altered its traditional linear demand and supply dichotomy. Since the 1990s in Australia, state and federal governments have progressively been devolving from centralized monopoly electricity markets, encouraging deregulation and removing often hidden subsidies (Byrnes et al., 2013; Grösche & Schröder, 2014)Coinciding with government deregulation of the electricity market has been the emergence of government policies and consumer preferences for energy from renewable sources that produce lower greenhouse gas (GHG) emissions delivering better environmental outcomes. Renewable energy, however, has traditionally been more expensive and therefore government policies encouraging electricity industry transformation towards renewables have increased the price of electricity to consumers (Byrnes et al., 2013; Grösche & Schröder, 2014). Such policies have fuelled the cost of electricity which has increased by more than 100 per cent in less than a decade (Nelson et al., 2012).

The convergence of electricity sector deregulation and policies that promote solar has resulted in major market upheavals with significant economic and social impacts (Grösche & Schröder, 2014; Nelson et al., 2011; Macintosh & Wilkinson, 2011). As renewable energy is continuing to be postulated as the future for global energy supply, it is important for negative consequences of policy to be mitigated. Understanding consumer motivation and decision making regarding solar photovoltaic (PV) uptake is important to ensure negative consequences including equity issues are able to be mitigated in future solar policy initiatives.

The consumer decision to acquire a solar PV system is a complex decision requiring information that the average consumer is unlikely to have in early stages of new technology (Guidolin & Mortarino, 2010). Yet, research into the uptake of energy technology by consumers is considered to be narrowly focused and does not address the full range of external factors that influence decision making (Faiers et al., 2007). This paper attempts to redress this by reporting on the cross-referencing of demographic data for the greater Brisbane metropolitan region in Queensland, Australia during the period from 2010 to 2014. Solar PV uptake during this time will be analysed to ascertain demographic aspects that may have influenced consumer behaviour. The need and importance of such research to track the influence of consumer behaviour and new trends in technology was a key finding of a review of the European Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe (REMODECE) project (de Almeida et al., 2011).

Policy drivers of consumer change

Much of the electricity market transformation has been driven by government policy. Some of this transformation relates to policies on improved labelling and energy efficiency of appliances to increase the efficient use of energy, whilst generous government subsidies for domestic solar hot water systems and solar PV systems were a major factor encouraging consumer uptake of this technology (Bahadori & Nwaoha, 2013). In Australia, there have been three key periods in the evolution of solar PV technology, government policy and consumer behaviour since 2001. During the period from 2001 to 2008 policy focussed on solar hot water systems and early incentives for solar PV. From 2008 to 2012 government policies encouraged a rapid uptake of solar PV while from 2012 onwards these policies have been wound back or discontinued. As a result, the dynamics of the traditional push-pull paradigm of transmission and distribution of the electricity market has transformed with consumers becoming producers and contributing to a demand-pull for technology.

In 2001, the Commonwealth of Australia introduced the Mandatory Renewable Energy Target (MRET) scheme to encourage investment in renewable energy technologies (Ferrari et al., 2012). During this period the Australian Government provided rebates to householders who acquired solar PV systems under the Photovoltaic Rebate Program (PVRP) which provided a fixed upfront incentive of about $5000 to reduce the capital cost of solar PV technology (Macintosh & Wilkinson, 2011). From 2007 most States and Territories commenced programs that offered the owners of small-scale solar PV installations generous Feed-in-Tariffs (FiTs) for electricity generated (Nelson et al., 2011). By the end of 2012 most of these State Government programs were scaled back or ended.

Table 4.1 summarises the growth of domestic solar hot water and solar photovoltaic (PV) systems in Australia since 2001. Commonwealth and State government policies and subsidies have been implemented at several stages of the solar energy production chain in Australia. During the period 2000-2008 the bulk of solar growth was in the form of solar thermal systems used for domestic water heating (Bahadori & Nwaoha, 2013). Since 2008 there has been a rapid uptake of small-scale solar PV systems on household rooftops. In five years from 2008 to 2013 the number of Australians installing solar photovoltaic (PV) technology grew from 8000 to more than one million (Flannery et al., 2013). In 2007, solar PV systems represented 9.6 MW of a 50,000MW power grid and in just four years this had increased by 100-fold to 1031 MW (Nelson et al., 2012).

Table 4.1: Small Scale Solar Installations 2001 to 2014

Installation year	Solar PV systems	Solar water heaters
2001	118	10,075
2002	251	21,839
2003	664	28,653
2004	1,089	30,991
2005	1,406	33,964
2006	1,115	35,924
2007	3,480	50,977
2008	14,064	85,385
2009	62,916	194,695
2010	198,208	127,093
2011	360,745	105,050
2012	343,320	69,466
2013	196,429	55,189
2014	28,788	6,801
Grand total	**1,212,593**	**856,102**

Source: Clean Energy Regulator 2014

The transformation of the residential consumer electricity market in the past decade has resulted in some consumers having greater choice in demand and supply of their power by being both consumers and producers of electricity sometimes coined prosumers (see for example, Grijalva & Tariq, 2011; Vogt, Weiss, Spiess, & Karduck, 2010). This revolutionary change is a major triple bottom line paradigm shift in electricity demand and supply which will have ongoing policy and regulatory implications with some consumers. However, this dynamic shift has not been universally enjoyed with a growing number of consumers experiencing energy poverty. Much of the research to date has focused on either the reasons for adoption or non-adoption of renewable energy (Caird et al., 2008) and not on the widening of the social divide between consumers which has been found to be an unfortunate outcome of these policies (Grösche & Schröder, 2014; Byrnes et al., 2013).

Evaluation of previous policy

Australian governments have adopted policies encouraging the rapid uptake of small rooftop solar PV systems through subsidies and generous Feed-in-Tariffs (FiTs). An unforeseen outcome of these policies has been an increase in the social divide between consumers, network stability and economic efficiency of technology (Byrnes et al., 2013). Although 11 per cent of the Australian population (about 2.6 million people) now use solar for their electricity, almost 89 per cent of the Australian population have not participated to date despite the generous financial incentives to uptake solar PV. An evaluation of the Australian Government solar PV incentive programs focusing on uptake of renewable energy, industry impact, emissions abatement and equity concluded the programs were ineffective and costly and resulted in equity issues (Byrnes et al., 2013; Macintosh & Wilkinson, 2011). In Germany, a significant adopter of domestic solar PV, Grösche and Schröder (2014) identified similar equity concerns with solar PV policy that resulted in the transfer of income from lower socio-economic groups to higher socio-economic groups.

Infrastructure costs associated with maintaining network stability were greater for small scale solar PV due to the multiple interfaces with the network for individual household PV units as opposed to the lower costs and economies of scale of the small number of interfaces required by large scale solar generation (Nelson at al., 2012; Macintosh & Wilkinson, 2011). Additional network costs were passed onto all consumers through higher network charges. The socially regressive aspects of these policies were that lower socio-economic groups who could not afford solar PV paid for network costs incurred by customers from higher socio-economic groups (Byrnes et al., 2013; Nelson at al., 2011; Macintosh & Wilkinson, 2011; Grösche & Schröder, 2014). In addition, home ownership was found to be the key factor influencing the ability of consumers to install solar PV. Critics of these policies identified that people who lived in rented accommodation or in apartments were unable to install solar PV with the result of a further transfer of income from lower socio-economic groups to higher socio-economic groups (Grösche & Schröder, 2014).

Reviews of past solar PV policies using a variety of measures of significance and datasets have reached similar conclusions that financial resources of households influence solar PV uptake due to the upfront costs of acquiring a residential solar PV and may have excluded many low to medium income households from programs (Grösche & Schröder, 2014; Nelson et al., 2011; Macintosh & Wilkinson 2011).This research also identified that households with higher levels of education and in higher skilled occupations were more likely to find it easier to access information on residential solar PV systems highlighting other equity issues in the design of solar policy (Grösche & Schröder, 2014; Nelson et al., 2011; Macintosh & Wilkinson 2011).

However, this current study uses demographic data for the greater Brisbane metropolitan area in south east Queensland to explore other explanatory variables such as the age of persons and family status that build on previous research (Byrnes et al., 2013; Nelson et al., 2012; Macintosh & Wilkinson 2011 in which education, financial capacity and home ownership status were seen as being the key explanatory variables to solar PV acquisition.. The demographic variables used in this research are based on selected census data that categorises the socio-economic characteristics of the population such as age, education, income, size of family and housing type. Solar electricity programs were selected because of the significant uptake by consumers with almost 11 per cent of the Australian population now using this technology for their electricity needs. Within Australia, the state of Queensland has the largest number of solar photovoltaic installations of any state.

Table 4.2: Domestic solar PV south east Queensland 2008 to 2014

Installation year	Solar PV systems
As at July 2008	533
As at July 2009	5947
As at July 2010	27,100
As at July 2011	83,188
As at July 2012	157,849
As at July 2013	229,439
As at July 2014	264,807

Source: Energex 2015

The data on the uptake of solar PV in south east Queensland (Table 4.2) showed there were 533 solar PV installations as at July 2008 when high solar FiTs ($0.44 per kWh) were in legislated by the State Government. By July 2012 when high solar FiTs ended, this had increased to 157,849. Since July 2012 when both legislated and industry-based solar FiTs was $0.06 to $0.08 per kWh, there has been a continuing growth in the numbers of solar PV installations.

Table 4.3: Solar installations and Median Weekly Income

	Rank	Postcode	Median weekly income	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4069	$2,347	3.26%	6.58%	13.10%	19.68%	22.70%
	2	4065	$2,286	2.51%	4.41%	8.15%	12.87%	14.63%
	3	4156	$2,265	4.11%	8.54%	16.97%	29.82%	35.62%
	4	4154	$2,261	2.58%	6.95%	15.76%	26.59%	31.78%
	5	4155	$2,230	6.29%	10.57%	22.00%	37.14%	43.43%
Middle	55	4165	$1,478	5.06%	11.08%	19.46%	28.17%	32.36%
	56	4101	$1,475	1.27%	2.13%	3.83%	5.65%	6.25%
	57	4173	$1,474	2.98%	6.91%	13.95%	20.39%	23.88%
	58	4179	$1,465	4.07%	7.35%	13.78%	19.81%	22.38%
	59	4159	$1,462	5.65%	10.95%	19.44%	28.03%	31.97%
Bottom	113	4303	$855	1.88%	4.91%	10.48%	14.45%	16.47%
	114	4205	$848	3.90%	10.47%	22.27%	27.55%	31.40%
	115	4183	$801	2.04%	5.34%	9.43%	14.37%	15.90%
	116	4507	$747	4.34%	12.42%	21.01%	27.36%	30.34%
	117	4184	$598	7.88%	13.34%	19.54%	25.11%	27.52%

The focus of this study (the greater Brisbane area) has almost one-half of the total Queensland population (1,920,205) (ABS, 2013). Data for solar energy programs has been collected for more than a decade based on postal areas and this research captures these based on annual uptake of different solar energy programs. As a result of exploratory research shown in Table 4.3, questions were raised about previous policy analysis and socio-economic conclusions on uptake of solar PV.

Due to these inconsistencies, a statistical analysis of key variables will be undertaken to identify the significance of explanatory demographic variables on uptake of solar PV. Three methods of analysing the demographic data (explanatory variables) will be used at annual intervals to examine the information and the results compared for policy implications. With a continuing focus on future investment in renewables and solar technology there is a need to identify socially regressive issues of previous solar policies. This research seeks to employ three methods of analysing a large sample of statistical demographic data (explanatory variables) at annual intervals to examine the significant demographic influences on uptake of solar PV during the period from 2010 to 2014 and to re-examine previous socio-economic conclusions.

Method

The target population for inference from this research is the greater Brisbane area of Australia with a population of more than 1.9 million people and the highest levels of solar installations in the nation. This area comprises 117 postal areas (postcodes) which is a commonly used level of data collection and analysis used by multiple agencies in Australia and allows for data comparison. Much of this information is publicly available as the postal code scale is large enough that individual consumers cannot be identified. Although research using ABS postcode level data does not capture the individual socio-economic profile of a consumer it was the best available socio-economic status (SES) measure as it captured the economic and social resources of the postal areas (Macintosh & Wilkinson 2011).

The demographic data for this research was obtained from the Australian Bureau of Statistics (ABS) from the 2011 Census (ABS, 2013). Table 4.4 shows the demographic information used for this study which includes: median weekly income; median mortgage payments; median weekly rent; population; dwelling type; ownership status; number of bedrooms and education status (university or tertiary). Data on solar installation was obtained from the Australian Government Clean Energy Regulator (AGCER) (AGCER, 2014) and local electricity distributor Energex which was then allocated to postal areas using postcode information from the ABS. The AGCER data accumulated solar installations annually over a period of 12 years from 2001 to 2012. The Energex data provided information for the 117 postal areas from 2008 to 2014 which could be cross-validated with the AGCER data.

Table 4.4: Explanatory variables

Socio-economic variables	Definition (ABS)
People	Total number of persons in the postal area
Families	Two or more persons, one of whom is at least 15 years of age, who are related by blood, marriage (registered or de facto), adoption, step or fostering, and who are usually resident in the same household.
Income	Gross income from all sources
Education	Number of persons with a university or tertiary qualification
Over 55 years	Persons aged over 55 years old
Over 65 years	Persons aged over 65 years
Owners	Own a dwelling outright or with a mortgage
Renters	Renting a dwelling
Mortgage	Housing loan repayments being paid on a monthly basis by a household to purchase the dwelling
Rent	Dollar amount of rent paid by households on a weekly basis for the dwelling
Private homes	Number of all private dwellings
Houses	House which stands alone in its own grounds separated from other dwellings by at least half a metre
Units	Includes flats, units and apartments - dwellings that do not have their own private grounds and usually share a common entrance foyer or stairwell
Duplexes	Semi-detached dwelling including terrace house and townhouses - dwellings that have their own private grounds and no other dwelling above or below them
Three bedrooms or more	Occupied private dwellings with three or more bedrooms

Source: ABS Census Directory http://www.abs.gov.au/ausstats/abs@.nsf/0/4B6D4A6E729E8275CA25720900078321?opendocument accessed 13 March 2015

A stratified sample was obtained for an exploratory data analysis which allows researchers flexibility in examining the data. Using this approach the data exploration for this project begins with simple statistical techniques to 'get to know' the data and to these then guide whether a more complex model is required, and if so, which model (Putler & Krider, 2012). This preliminary analysis sorted solar installations based on different ABS variables, namely: median weekly income, education, home ownership or rental status, housing type and bedrooms. The five top, middle and bottom postcodes from the sample were then selected for analysis. Table 4.3 shows solar installations based on median weekly income. The sample dataset was analysed using two approaches. First an exploratory study was undertaken to examine the obtained data and results of previous literature. Second, a statistical analysis was performed using two types of decision trees, namely classification and regression trees (CART) and boosted regression trees (BRT). These were obtained via the RPART and GBM packages in the free R software which is widely used for statistical analysis, classification and clustering (R-Foundation, 2014). The CART and BRT analyses are described in more detail below. The R code is provided in the Supplementary material.

The exploratory data analysis stage of the research ranked each of the 117 postal areas based on each demographic characteristic to examine the relative influence on solar installations. Tables 4.3, 4.5, 4.6, 4.7, and 4.8 are examples of this. The top, middle and bottom five postal areas were identified and compared against the results in previous literature that identified socio-economic influences on uptake of solar PV. Based on this preliminary correlation of demographic information and solar PV installation data, differences were identified and a further analysis of the information was undertaken using classification and regression tree (CART) models.

Decision models are general purpose prediction and classification mechanisms that are used in a range of data mining and knowledge discovery (de Ville, 2013). These models provide a simple to understand representation of the relationship between a response variable (solar PV) and potential explanatory variables (selected demographic) and are accepted in many fields of research because they can identify and interpret complex hierarchical relationships (Hu et al., 2011). Decision tree models aim to segment the data into a set of subgroups, where the responses within each subgroup are similar. The subgroups are formed by selecting a set of variables and a series of binary splits of these variables, until a specified stopping rule is reached. In the current study, the aim is to create subgroups of postal areas based on similar percentages of uptake of solar PV. The method first determines the variable and the splitting point that provides the best division of postal areas into two groups (higher and lower solar PV uptake), then within each group it identifies the next variable that splits into two subgroups, and so on until the stopping rule is reached. The result is usually depicted as a tree-like structure with the splitting variables as nodes in the tree, the binary splits as branches of the tree, and the subgroups of postal PVs as the terminal nodes. In the current study, the model provided the average solar PV uptake per person in the postal PVs in each of the terminal subgroups. As indicated above, two types of trees were used in this research. The first type is a classification and regression tree (CART) that is a single decision tree based on the full dataset and shows the set of most influential predictor variables. The second type is a boosted regression tree (BRT) which constructs many small trees based on subsets of the data and shows the relative influence of the variables. The construction and interpretation of these trees are described in more detail in the Results section. Decision trees represent information in a way that is simple to interpret and easy to visualise with predictor variables able to be of any type and scale of measurement (McCluskey et al., 2014).

Decision tree methods such as CART and BRT are very well established statistical and machine learning techniques (Hastie, Tibshirani, & Friedman, 2009) and are often preferred over more traditional linear regression techniques because of their ability to describe non-linear relationships and interactions between variables and the response. Furthermore, these models accommodate correlated variables more easily. It should be noted that decision trees do not provide a p-value as in traditional linear regression, but instead provide a measure of the relative importance of the variables in the model. In decision tree analysis the analogue of the p-value reported in standard linear regression is the relative weight of the variable in the model. More detail of the construction and interpretation of the trees is given in the Results section. . Other methods were considered, however in this research the variables are highly correlated and it was anticipated that there would be non-linearities in the response and interactions between the variables that would be difficult to represent using other methods of regression. The chosen decision tree approach allowed for greater exploration of non-linearities and interactions.

Results

Exploratory data analysis

Explanatory variables for this study were derived from selected demographic information including socio-economic, education and home ownership status and then compared with the response variable, solar PV. Each explanatory variable was ranked and was assessed and compared to the percentage of solar PV installations. Previous literature reported positive correlation between financial capacity and solar installations (Nelson et al., 2011, Nelson et al., 2012). However, the data in Table 3 shows similar levels of solar PV across each of the groups regardless of income. Additionally, previous literature identified a relationship between education and access to information as key factors in higher uptakes of solar PV (Caird et al., 2008). The exploratory assessment undertaken in Table 4.5 identified very low rates of installation of solar PV in postal areas with the highest numbers of university/tertiary educated persons, whereas the areas with the lowest levels of university/tertiary educated persons had more than double the installation rates of solar PV. However, the postal areas with the highest numbers of university/tertiary educated persons were also areas with high concentration of units and apartments.

Table 4.5: Solar installations and Tertiary Education

	Rank	Postcode	Education University/ Tertiary	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4111	561	72.2%	2.07%	5.18%	12.18%	16.32%	18.91%
	2	4067	3,462	70.1%	1.11%	1.80%	3.17%	5.00%	5.67%
	3	4066	3,174	52.7%	1.22%	2.03%	3.50%	5.34%	5.98%
	4	4059	2,303	51.7%	1.30%	2.45%	4.56%	7.02%	7.93%
	5	4068	3,846	46.5%	1.46%	2.55%	4.98%	7.76%	9.08%
Middle	55	4119	251	15.6%	3.55%	8.99%	19.89%	30.42%	35.51%
	56	4055	905	15.3%	4.00%	8.55%	16.63%	25.44%	29.63%
	57	4123	667	14.8%	3.20%	7.91%	15.27%	23.01%	27.55%
	58	4054	516	14.7%	2.86%	6.22%	12.40%	18.56%	21.69%
	59	4130	338	14.3%	5.40%	10.62%	21.85%	33.09%	37.74%
Bottom	113	4303	74	5.4%	1.88%	4.91%	10.48%	14.45%	16.47%
	114	4508	321	5.3%	2.51%	6.39%	12.62%	19.04%	22.72%
	115	4114	601	5.3%	1.68%	3.90%	8.03%	11.18%	13.19%
	116	4132	363	4.9%	2.64%	7.08%	15.75%	21.58%	25.10%
	117	4184	70	4.5%	7.88%	13.34%	19.54%	25.11%	27.52%

Table 4.6: Solar installations and Home Ownership

	Rank	Postcode	Owners	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4155	288	90.8%	6.29%	10.57%	22.00%	37.14%	43.43%
	2	4156	786	88.9%	4.11%	8.54%	16.97%	29.82%	35.62%
	3	4037	2,037	85.9%	3.72%	7.68%	17.94%	28.24%	33.07%
	4	4035	6,452	84.1%	4.37%	8.82%	17.10%	26.55%	31.26%
	5	4069	9,048	83.6%	3.26%	6.58%	13.10%	19.68%	22.70%
Middle	55	4503	8,024	66.1%	2.29%	6.28%	14.02%	21.72%	26.34%
	56	4507	4,948	65.8%	4.34%	12.42%	21.01%	27.36%	30.34%
	57	4158	957	65.7%	3.14%	6.15%	11.56%	15.68%	17.90%
	58	4078	4,993	65.5%	2.99%	8.94%	17.64%	25.50%	29.20%
	59	4172	923	65.3%	2.75%	5.37%	12.50%	18.00%	20.42%
Bottom	113	4169	2,116	40.5%	0.71%	1.16%	2.19%	3.55%	4.24%
	114	4102	915	38.2%	1.79%	3.33%	6.77%	9.06%	10.46%
	115	4101	2,850	37.1%	1.27%	2.13%	3.83%	5.65%	6.25%
	116	4000	2,002	36.4%	0.33%	0.54%	0.76%	1.15%	1.43%
	117	4006	2,292	34.5%	0.18%	0.37%	0.76%	1.24%	1.43%

The summary figures in Table 4.6 indicate that home ownership is a factor in solar PV uptake which supports previous research and literature (Macintosh et al., 2011). Tables 4.7 and 4.8 indicate a relationship between areas with the highest concentrations of persons who rented or lived in apartments and lower rates of solar PV installations. This would appear to further support a positive correlation between home ownership and PV installation.

Table 4.7: Solar installations and Renters

	Rank	Postcode	Renters	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4006	4,197	63.2%	0.18%	0.37%	0.76%	1.24%	1.43%
	2	4101	4,556	59.4%	1.27%	2.13%	3.83%	5.65%	6.25%
	3	4000	3,260	59.3%	0.33%	0.54%	0.76%	1.15%	1.43%
	4	4102	1,296	58.2%	1.79%	3.33%	6.77%	9.06%	10.46%
	5	4169	2,983	56.7%	0.71%	1.16%	2.19%	3.55%	4.24%
Middle	55	4163	1,918	33.2%	3.48%	7.60%	11.89%	17.33%	19.58%
	56	4078	2,515	33.0%	2.99%	8.94%	17.64%	25.50%	29.20%
	57	4133	1,626	33.0%	2.96%	8.86%	15.84%	22.18%	26.24%
	58	4111	112	32.7%	2.07%	5.18%	12.18%	16.32%	18.91%
	59	4018	1,163	32.0%	1.73%	5.26%	12.12%	18.42%	21.98%
Bottom	113	4125	320	13.6%	3.38%	8.86%	18.93%	27.22%	31.69%
	114	4037	306	12.9%	3.72%	7.68%	17.94%	28.24%	33.07%
	115	4035	985	12.8%	4.37%	8.82%	17.10%	26.55%	31.26%
	116	4006	4,197	63.2%	0.18%	0.37%	0.76%	1.24%	1.43%
	117	4101	4,556	59.4%	1.27%	2.13%	3.83%	5.65%	6.25%

Table 4.8: Solar installations and Units, Flats, Apartments

	Rank	Postcode	Units, Flats, Apartments	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4000	4,593	83.6%	0.33%	0.54%	0.76%	1.15%	1.43%
	2	4006	5,472	82.4%	0.18%	0.37%	0.76%	1.24%	1.43%
	3	4007	5,472	82.4%	1.05%	1.63%	2.78%	4.88%	5.75%
	4	4005	3,681	70.8%	0.64%	1.10%	2.21%	3.66%	4.04%
	5	4169	3,318	63.5%	0.71%	1.16%	2.19%	3.55%	4.24%
Middle	55	4157	277	4.2%	3.80%	8.30%	16.16%	23.52%	27.11%
	56	4305	864	4.2%	2.41%	5.91%	13.01%	19.83%	22.91%
	57	4021	146	4.0%	2.51%	6.03%	13.17%	18.71%	22.95%
	58	4173	125	4.0%	2.98%	6.91%	13.95%	20.39%	23.88%
	59	4054	175	3.6%	2.86%	6.22%	12.40%	18.56%	21.69%
Bottom	113	4164	4	0.1%	5.00%	10.25%	18.54%	29.02%	33.70%
	114	4117	0	0.0%	1.64%	6.54%	18.22%	23.60%	27.10%
	115	4130	0	0.0%	5.40%	10.62%	21.85%	33.09%	37.74%
	116	4154	0	0.0%	2.58%	6.95%	15.76%	26.59%	31.78%
	117	4155	0	0.0%	6.29%	10.57%	22.00%	37.14%	43.43%

A number of issues of significance were identified by the exploratory analysis of single and multiple variables. It re-confirmed links identified in previous literature such as the links between private home ownership and solar PV uptake. The exploratory analysis identified that tertiary education and the financial capacity of individuals did not appear to be as significant as identified by previous literature. New information revealed by the exploratory analysis was the number of bedrooms of home and the type of dwelling were significant explanatory variables in solar PV uptake. Based on the perceived differences between the published literature and the new information revealed justified the further analysis of the information. This was undertaken using decision tree (CART and BRT) models, since these are specifically designed to identify interactions between variables.

CART analysis

The CART analyses generated decision trees similar to the one depicted in Figure 4.2.

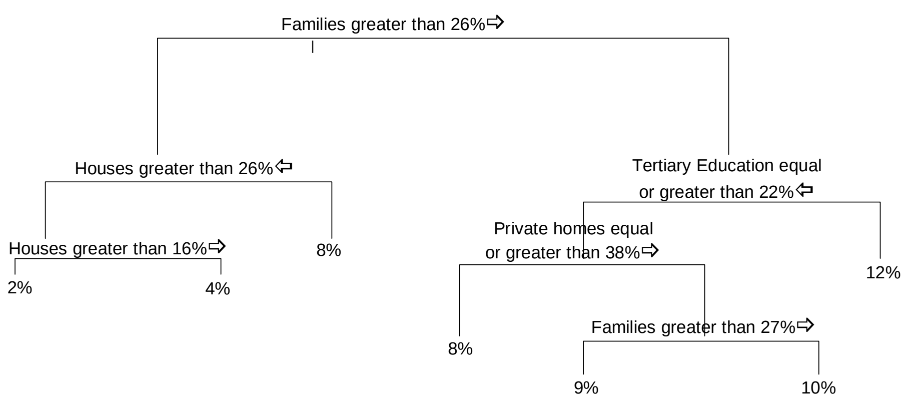

Figure 4.2 Decision Tree 2014

The CART model shown in Figure 4.2 describes the inter-relationship between explanatory variables for a specific year when the data was modelled with solar PV uptake as the response variable. The top down graphical display used by this model provides a visual of the strongest branch produced by the software with the first level reflecting the variable that provides the greatest influence on the data under examination (de Ville, 2013). In a CART the flow of the right branch is conditional of the node being *true* whilst the left is conditional on the node being *false* (Morgan, 2014). An example of the CART used for this project is Figure 4.2 for the year 2014 which reveals the important variables associated with solar uptake. The example for 2014 identifies *Families* as the most influential branch of the data and if the percentage of Families in each postcode is greater than 26% the direction of significance is to the right. Conditional on the percentage of Families being greater than 26%, the next most influential feature in the CART for 2014 is Tertiary Education. The numbers at the bottom of each terminating branch indicates the mean uptake of solar per person. In this case, if the percentage of Families in a postal area was greater than 26% and these postal areas had a level of Tertiary Education greater than 22% the uptake of solar PV per person in these postal areas based on these two variables alone was 12%. Using this example further, where the percentage of Families is less than 26% the branch goes to the left and the next most significant feature in these postal areas is *Houses.* The uptake of solar PV per person based on these two variables in these postal areas was 8%. This example demonstrates the importance of identifying the multiple contributions which may be required to effectively explain an outcome (de Ville, 2013).

The CART decision tree analysis showed that at the mid-point of the $0.44 solar FiT policy (July 2010), the most influential demographic feature in the uptake of solar PV was families of two or more persons. The decision tree summary (Table 4.9) identified that the strongest differentiation in solar uptake was people aged over 55 years, followed by persons who owned their own homes and privately owned dwellings. However, by July 2012, when $0.44 solar FiTs ended in Queensland, the most influential explanatory variable impacting on solar PV uptake was the size of the dwellings with three or more bedrooms, with people aged over 55 years continuing to be a strong explanatory variable. Four of the five strongest explanatory variables in 2012 related to the type of dwelling or its ownership. By 2014, two years after the end of $0.44 solar FiTs the primary explanatory variable was families of two or more persons, with education emerging as an important explanatory variable.

Table 4.9: CART significance of explanatory variables as ranked by R program

Significance	July 2010	July 2011	July 2012	July 2013	July 2014
1	Families	Families	Three Bedrooms	Three Bedrooms	Families
2	Over 55	Over 55	Over 55	Families	Houses
3	Houses	Houses	Houses	Houses	Education
4	Owners	Private homes	Private homes	Education	Private homes
5	Private homes		Owners	Private homes	

These analyses highlighted the inter-relationship between the explanatory variables indicating that combination of issues can be significant in determining the influence of socio-economic factors on the uptake of the response variable, solar PV.

Boosted regression tree (BRT) analysis

The BRT analysis was undertaken to show the relative influence of the explanatory variables on solar PV uptake. Figure 4.3 is an example of the BRT produced by the R program for the data for the year 2014 while Figure 4.4 summarizes the results from the analysis of all the BRT's undertaken on the annual data from 2010 to 2014.

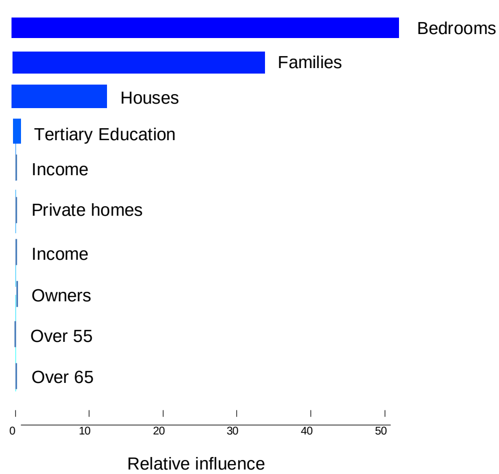

Figure 4.3 Boosted regression tree 2014

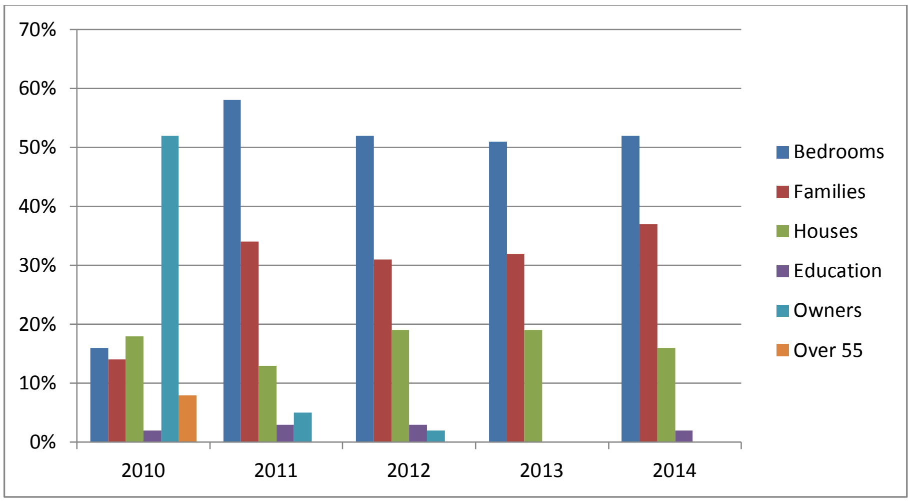

Figure 4.4: Summary of boosted regression tree relative influence 2010 to 2014

The examination of the relative influence of the explanatory variables as predictors shows that dwellings with three or more bedrooms, families of two or more person and houses reoccurred in most years. This generally correlated with the explanatory variables in the CART analysis.

Summary of the three studies

Three different types of analysis were undertaken in this study. The exploratory analysis which ranked each explanatory variable and compared it with the response variable (solar PV), identified differences with the published literature (Tables 4.3, 4.5, 4.6, 4.7 and 4.8). The CART analysis identified explanatory variables that had not been mentioned in previous literature such as being aged over 55 and families with two or more persons. It also showed that having a tertiary education was less important. The boosted regression tree analysis confirmed the relative importance of the explanatory variables in the CART analysis.

Discussion and policy implications

Previous research on the factors that influence uptake of solar PV have asserted financial capacity and home ownership as important pre-requisites (Byrnes et al., 2013; Nelson et al., 2012; Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011), along with groups of people who were unable to install solar PV due to their living arrangements such as renting (Byrnes et al., 2013). Acknowledging these assumptions about solar PV uptake, this research sought to introduce a wide range of socio-economic explanatory variables to examine the significance of specific socio-economic variables and whether these had linkages to other variables.

The correlation of the three analyses identified issues that have not been uncovered previously. Whilst home ownership was affirmed as a key explanatory variable in solar PV uptake, the significance of people aged over 55 years and families were also highlighted. In addition, having a tertiary education associated with better knowledge of technology was found to be a less significant factor in solar PV uptake than in previous research. This study also questions previous research where financial capacity was significant in uptake of solar PV (Byrnes et al., 2013; Nelson et al., 2012; Macintosh & Wilkinson, 2011). Income was not found to be a significant explanatory variable in any of the three analyses, with Table 4.3 showing the five lowest socio-economic postcode areas as having similar solar PV uptake rates as the top five postcode areas. Linkages between home ownership and financial capacity needs to be viewed cautiously based on this research as persons aged over 55 may own their own homes but may be on low incomes such as government or private pensions.

During the years of Queensland government policy support for $0.44 solar FiTs (2010 to 2012), the decision tree analysis showed that being aged over 55 years was one of the top three (3) explanatory variables and this was further detected in the 2010 BRT. People aged over 55 on pensions or fixed incomes may be concerned about the impact of increasing electricity prices and installed solar PV and identified the $0.44 FiT as a cost effective means of managing electricity costs for persons on fixed incomes such as pensions. Many of the postal areas with larger numbers of people aged over 55 years are also in the lower SES areas when cross referenced with median weekly income. In postal areas with high levels of units and high levels of people aged over 55 years, solar PV uptake was low. This would tend to indicate that persons aged over 55 years that live in units or rent were more likely to be excluded from solar PV. In terms of equity, people aged over 55 years that rent would be the most vulnerable to electricity price increases.

In many areas with lower levels of university/tertiary education and lower incomes, solar PV uptake was more than double suburban profiles with high incomes and high levels of university/tertiary education (Table 4.5). Previous research by Caird and colleagues (2008) indicated that knowledge was a critical feature in solar PV decisions. However, most of the postal areas with highest uptake of solar PV had the lowest levels of university/tertiary education. Conversely, in postcode areas with high levels of university/tertiary education, solar PV uptake was amongst the lowest. However, the postal areas with the highest numbers of university/tertiary educated persons were also areas with high concentration of units and apartments and any conclusions should take this into account.

Policy implications

This research reinforces some of the assumptions from previous literature on socio-economic variables that influence solar PV uptake, but identifies how other assumptions may not be as significant and how key socio-economic variables have been overlooked. Linkages between explanatory variables have been identified as being significant demonstrating that the model of solar PV uptake is a complex system with cause and effect that needs to be carefully examined.

The analysis reinforced previous conclusions that owning a dwelling was one of the significant explanatory variables for solar PV installation and that the dwelling was most likely to be a house occupied by a family of two or more persons. However, linkages with education and income were found to be less significant. New findings on the significance of being aged over 55 years highlight significant explanatory variables that may not have emerged in past research.

Although the policies that promoted $0.44 FiTs were available to the entire population, in reality this analysis identifies explanatory variables that may identify problems with the design of solar FiT policies. These policies may discriminate against people who do not own their own homes or those who live in dwellings that are not conducive to the installation of solar PV. The significance of people aged over 55 years may identify concerns by older people about electricity prices and the importance of policy measures that can assist these groups.

Conclusion

Rather than take for granted previous research on SES profile of consumers regarding socio-economic explanatory variables in solar PV uptake, the significance of this research is the re-examination of previous assumptions based on data covering almost two million people in one of the areas of greatest solar PV penetration in the world. This research scrutinized the results from previous research to ascertain the most significant explanatory variables in areas with high uptakes of solar PV and whether this changed over time and under differing policy settings. Additionally, this research sought to examine significance during and after solar PV policy interventions.

This research reaffirmed the significance of home ownership as being a significant socio-economic explanatory variable in solar PV uptake. However, it also showed the significance of the linkages between socio-economic explanatory variables in solar PV uptake and the methodology used identified explanatory variables that had not been discussed in previous literature. Although previous research identified education and knowledge as an important explanatory variable this was found to be less significant. However, this study showed the importance of explanatory variables such as being aged over 55 years that had not been identified in previous research.

The research methodology used for this study and analysis shows the importance of cross referencing different research methodologies to identify socio-economic variables and how they may change over time and under different policy settings. It reinforces that much of the previous research and subsequent policy tends to concentrate on financial, regulatory and information drivers (Caird et al., 2008) and that social context needs to be more fully explored. The use of multiple systems of analysis across large data collections used in this research provides for a greater contextual understanding of the phenomena of solar PV uptake. Discerning the highlighted explanatory variables further is an area for future research but one that will require clear understanding of the complexity of the decision to acquire solar PV.

In addition to elucidation of insights about the effect of socioeconomic influences on solar PV update, this paper also makes a methodological contribution to the field. Specifically, it introduces a complementary quantitative rigour to existing qualitative approaches that seek to understand social dimensions of this important problem. Moreover, the use of multiple models in an ensemble learning approach is of growing interest in the statistical and machine learning communities. This is the first time that CART methods have been employed to investigate this complicated, and indeed statistically complex, problem. Although the results from the data should not be generalised to other jurisdictions, the methodology used provides a guide to other researchers using statistical data to further explore socio-economic trends in uptake of solar PV.

This paper makes a contribution to the field of energy policy by reviewing a range of external factors that influence decision making of consumers in the uptake of energy technology and also by highlighting some of the negative consequences including equity issues that need to be mitigated with such policies.

Supplementary material

R-software setup commands

```
library(rpart)
attach(datafile)
head(datafile)
summary(datafile)
mean(Income, na.rm=TRUE)   # mean
median(Income, na.rm=TRUE)   # median
sd(Income, na.rm=TRUE)  # standard deviation
datafile.p <- datafile/People
attach(datafile.p)
head(datafile.p)
summary(datafile.p)
```

Plot commands 2014 Solar data

```
j1=lm(datafile.p$Solar2014~datafile.p$Income+datafile.p$People+datafile.p$Families+datafile.p$Privatehomes+datafile.p$Owners+datafile.p$Houses+datafile.p$Threebedrooms+datafile.p$Education+datafile.p$Over55+datafile.p$Over65)
summary(j1)
predict.lm(j1,datafile.p)
plot(datafile.p$Julfour,predict.lm(j1,datafile.p))
lines(seq(0,.4,.01),seq(0,.4,.01))
```

Decision Tree 2014 Solar data

```
j2=rpart(datafile.p$Julfour~datafile.p$Income+datafile.p$People+datafile.p$Families+datafile.p$Private+datafile.p$Owners+datafile.p$Houses+datafile.p$Threebedrooms+datafile.p$Education+datafile.p$Over55+datafile.p$Over65, cp=0.01)
plot(j2)
text(j2, xpd=NA)
```

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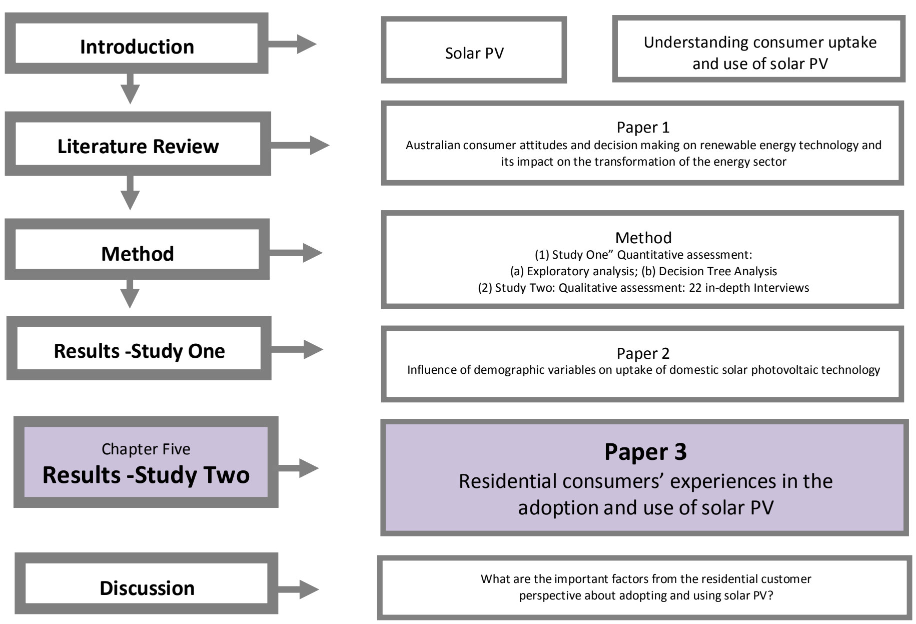
Chapter 5: Paper 3 – Qualitative Assessment

5

This chapter reports on the in depth quantitative analysis of 22 persons under different solar FiT policy settings to explore their acquisition and energy use behaviour of solar PV. It examines the lived experiences of the people who acquired and are using solar PV and how these lived experiences may provide insight into understanding solar PV policy from the residential customer perspective. This paper makes a contribution to knowledge that would aid in the design of more effective and equitable renewable energy policies. This chapter has been submitted to Energy Policy and is presented here in the format submitted for that journal.

Figure 5.1 Relationship between this chapters and thesis



Statement of Contribution of Co-Authors for Thesis by Published Paper

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The following is the suggested format for the required declaration provided at the start of any thesis chapter which includes a co-authored publication.

The authors listed below have certified* that:
1. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit, and
5. they agree to the use of the publication in the student's thesis and its publication on the Australasian Research Online database consistent with any limitations set by publisher requirements.
In the case of this chapter:

Contributor	Statement of contribution
Jeff Sommerfeld	• Doctoral Student, School of Design, Queensland University of Technology (QUT) • Chief investigator, significant contribution to the planning of the study, literature review, data collection and analysis and writing of the manuscript.
Laurie Buys	• Professor, School of Design, Queensland University of Technology (QUT) • Significant contribution in the planning of the study (as associate supervisor) and assisted with data interpretation, preparation and evaluation of the manuscript.
Desley Vine	• Research Fellow, School of Design, Queensland University of Technology (QUT) • Significant contribution in the preparation and evaluation of the manuscript.

Principal Supervisor Confirmation

I have sighted email or other correspondence from all Co-authors confirming their certifying authorship.

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Abstract:

Public policy in many nations is seeking to transition energy generation towards renewable sources such as solar photovoltaic (PV). Reviews of past policy aimed at increasing consumer acceptance of renewable energy sources have identified policy implementation may not align with policy objectives of energy professionals. The research and analysis of consumers and their interaction with solar PV policy is important in assessing policy outcomes and how these can be better delivered or adapted. This paper reports on an in depth qualitative analysis of 22 persons under different feed-in tariff (FiT) policy settings to explore consumer experiences in acquiring solar PV and their energy use behaviour. The responses of participants indicate there were different motivations and energy use behaviour based on the policy in which solar PV was acquired and these may provide insight into policy development or follow up studies.

Key words: solar photovoltaic (PV), demographic variables, feed-in tariff (FiT),

Abbreviations: Feed-in tariff (FiT); Greenhouse gas (GHG); photovoltaic (PV); renewable energy sources (RES);

Introduction:

Worldwide, public policy focusing on reducing pollution and greenhouse gas (GHG) emissions and expanding the uptake of electricity from sustainable resources has initiated a major transition in the generation and supply of electricity (Stigka, Paravantis, & Mihalakakou, 2014). Policies aimed at increasing consumer acceptance of renewable energy sources (RES) in the residential sector are being used as key contributors to GHG mitigation (Sardianou & Genoudi, 2013). Solar photovoltaic (PV) including feed-in tariffs (FITs), low-interest loans, investment subsidies and other incentives have been used as mechanisms to support the diffusion of renewable energy technologies to domestic households (Del Río & Mir-Artigues, 2012). Consequently, there has been a shift away from an electricity supply model based on central power stations and distribution to smaller-scale power generation at the household level. This worldwide shift is transformational, turning the electricity supply and transmission system upside down (Chapman, McLellan, & Tezuka, 2016; Sauter & Watson, 2007).

The success of policies that encourage the uptake of renewable energy requires consumer acceptance and engagement with new and emerging energy technologies such as solar PV (Devine-Wright, 2007; Sardianou & Genoudi, 2013; Sauter & Watson, 2007; Willis, Scarpa, Gilroy, & Hamza, 2011). To maximise the implementation of transformational energy policy, the role of the consumer is critical as their use of renewable technology may, or may not, align with policy objectives of the energy professionals or have consequences that are not yet considered (DeCicco, Yan, Keusch, Muñoz, & Neidert, 2015). The research and analysis of consumers and their interaction with renewable energy policy is important in assessing policy outcomes and how policies can be delivered or adapted (Greene, 2013). Such an understanding and responsiveness to consumer interaction with renewable energy technology would allow for policy options to be adapted to address technical or human related issues that impact on the effectiveness of public policy (Kanellakis, Martinopoulos, & Zachariadis, 2013). The purpose of this study is to examine residential consumer experiences in acquiring and using solar PV and how the experiences of these consumers may provide insight that aids the development of solar PV policies.

Solar PV in Australia

Australia has one of the highest average solar irradiation levels of any continent in the world, with a 1 kW household solar photovoltaic (PV) system having an average generation potential of 1460 kWh per annum (Chapman et al., 2016). In 2001, the Australian Government introduced the Mandatory Renewable Energy Target (MRET) scheme to encourage investment in renewable energy technologies (Ferrari, Guthrie, Ott, & Thomson, 2012). The scheme was divided in 2010 into two parts: the Large-scale Renewable Energy Target (LRET) and the Small-scale Renewable Energy Scheme (SRES). During this period the Australian Government provided rebates to householders who acquired solar PV systems (Macintosh & Wilkinson, 2011). The SRES provided a fixed upfront incentive of approximately $5000 to reduce the capital cost of solar PV technology. In addition, most States and Territories offered the owners of small-scale solar PV installations a Feed-in-Tariff (FiT) that paid households for electricity generated that was funded by all electricity customers within the local network (Chapman et al., 2016; Nelson et al., 2012). As a result of consumer demand and government policies and incentives, Australia has one of the highest rates of solar PV adoption in the world, with as many as two million householders having 'solar rooftops' (Simpson & Clifton, 2015). In just four years, between 2007 and 2011, the cumulative installed capacity of solar PV units increased 100-fold from nearly 10MW to more than 1000MW (Nelson et al., 2012).

Solar PV in Queensland

By the end of 2012, Queensland, known as the "Sunshine State", had the highest up-take of solar, with almost one-third of all PV capacity in Australia, followed by New South Wales with 22% (Chapman et al., 2016; Flannery & Sahajwalla, 2013). From 2008 to 2012, public policy in Queensland provided additional incentives for consumers to acquire solar PV through a solar FiT of $0.44, equalling $440 MWh (Nelson et al., 2012). Consumers were also eligible for the national SRES rebate (Macintosh & Wilkinson, 2011). In July 2008 there were 533 solar PV installations in south east Queensland which grew to 157,849 by July 2012 (Table 5.1). In July 2012 a policy change occurred, with the Queensland government guaranteed solar FiT of $0.44

ceasing. The current solar FiT is determined by the market which pays on average $0.06 for each kilowatt of power exported to the grid.

Table 5.1. Domestic solar PV south east Queensland 2008 to 2014

Installation year	Solar PV systems
As at July 2008	533
As at July 2009	5947
As at July 2010	27,100
As at July 2011	83,188
As at July 2012	157,849
As at July 2013	229,439
As at July 2014	264,807

Source: Energex 2015

Reviews of solar photovoltaic policy

The objectives of policies that encourage consumers to acquire solar PV are designed to increase the amount of renewable electricity used and reduce the reliance on electricity from the grid associated with GHG emitting power stations (Macintosh & Wilkinson, 2011; Nelson et al., 2011). Many of the reviews of Australian solar programs acknowledge the success of solar PV policies in the development of the solar PV industry (Macintosh & Wilkinson, 2011; Nelson et al., 2011). However, these reviews have also identified adverse impacts such as solar PV policy being costly, socially regressive and environmentally ineffective. Solar PV has been identified as having a high generation cost of energy, requiring generous support mechanisms to be competitive with fossil fuel generation (Chapman et al., 2016). The solar PV FiTs used to incentivize consumers to acquire solar PV are criticized by some researchers because they are funded through increased electricity prices impacting on lower income groups who are less capable of investing in solar technology (Chapman et al., 2016; Nelson et al., 2011). Previous research has also identified that households with higher levels of education and in higher skilled occupations were more likely to find it easier to access information on residential solar PV systems highlighting other equity issues in the design of solar policy (Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011; Nelson et al., 2011). Questions have also been raised about the environmental benefits from past government incentives to solar PV due to a limited reduction of GHG emissions from traditional electricity sources (Macintosh & Wilkinson, 2011; Nelson et al., 2011). Some researchers have identified some consumers have not decreased their use of power but rather changed it to other times to maximise benefits from solar FiTs. Based on the electricity supply profile of south east Queensland (Nelson et al., 2012), this type of behaviour is most likely to increase peak demand and increase supply of electricity during off-peak periods.

Solar photovoltaic and consumers

Many of the past examinations of solar PV policy have been based on statistical data which identified consumer issues such as financial capacity, home ownership status and education (Byrnes et al., 2013; Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011). However, there appears to be little investigation into consumer motivation to adopt solar PV and subsequent behaviour that may provide insight into how consumers may impact on the successful outcomes of public policy. Much of the research on solar PV has been focused on technical, regulatory and information issues based on data at the national or international level and only identify consumer issues according to broad demographic definitions (Caird et al., 2007). Despite the awareness of the general importance of socio-economic variables that have arisen from these reviews of solar PV policy, there remains a knowledge gap about consumers and their impact on the effectiveness of solar policies. The literature on residential solar adoption, while growing, is still in early stages (Rai, Reeves, & Margolis, 2016).

The rapid uptake of solar PV technology by consumers has not only transformed the demand and supply dichotomy but also social and economic aspects of the electricity market. The purpose of this study is to examine consumers who acquired and are using solar PV in south east Queensland and how these lived experiences provide insight into understanding the response to solar PV policy from the residential customer perspective. This study takes an in depth examination of the ways that residential customers acquire and use solar PV and how this use may impact on the effectiveness of solar PV policies.

Method

This study was designed as a qualitative explorative field study using semi-structured in-depth interviews. Interviews are a commonly used social science methodology to allow the researcher to engage in a conversation with participants to explore their subjective opinion about a technology, its usefulness, and barriers to use (Connelly, ur Rehman Laghari, Mokhtari, & Falk, 2014). The use of qualitative methods in energy research enables the examination of personal narratives associated with everyday use of energy and energy-related practices (Bickerstaff, Devine-Wright, & Butler, 2015).

The interviews were carried out in 2015 with participants recruited from the south east Queensland region. Criteria for inclusion were based on the person having acquired a domestic rooftop solar PV system and being the principal decision maker for its acquisition. The age of participants was not a criterion although ethical clearance for the research required that participants be aged over 18 years old. Two cohorts of participants were identified for interview: those persons who acquired domestic rooftop solar PV during the period from 2008 to July 2012 at which time a solar FiT of $0.44 was guaranteed by government legislation; and those persons who acquired domestic rooftop solar PV after July 2012 at which time a solar FiT of $0.06 was payable based on market rates.

Participants who were likely to meet these criteria were approached in person and provided with standard information on the project together with information on ethical approval of the project from Queensland University of Technology's Office of Research Ethics and Integrity. Participants were then contacted to arrange an appointment for an interview in their homes. Prior to commencement of interviews, participants were provided with documents about the research and written consent was obtained. Interviews lasted from 45 to 60 minutes and these were electronically recorded.

Table 5.2. Solar interview participants

No.	FiT	Age	M/F	Dwelling	Occupants	Occupancy	Income	Education	Occupation
01	$0.44	58	F	House	2	35yrs	<$70k	PhD	Education
02	$0.44	60	M	House	2	10yrs	>$90k	Senior	Government
03	$0.44	53	M	House	4	10yrs	>$90k	PhD	Science
04	$0.44	34	M	House	2	8yrs	>$90k	Tertiary	Education
05	$0.44	88	F	Townhouse	1	15yrs	<$30k	Primary	Retired
06	$0.44	46	M	House	4	10yrs	>$90k	PhD	Education
07	$0.44	84	F	Townhouse	1	7yrs	<$50k	Senior	Retired
08	$0.44	81	F	Townhouse	1	22yrs	<$30k	Primary	Retired
09	$0.44	79	M	House	2	20yrs	<$50k	Primary	Retired
10	$0.44	68	F	House	1	4yrs	<$30k	Tertiary	Retired
11	$0.44	57	M	Townhouse	2	17yrs	>$90k	PhD	Education
12	$0.44	83	M	House	1	49yrs	<$30k	Primary	Retired
13	$0.06	60	F	House	3	3yrs	>$90k	Tertiary	Health
14	$0.06	53	M	House	2	2yrs	<$70k	Tertiary	Education
15	$0.06	62	M	House	2	12yrs	<$70k	Senior	Retired
16	$0.06	53	F	House	2	5yrs	>$90k	Senior	Travel
17	$0.06	63	M	House	2	15yrs	>$90k	Tertiary	Self-employed
18	$0.06	44	M	House	2	2yrs	<$70k	Tertiary	Professional
19	$0.06	33	F	House	5	6yrs	>$90k	Tertiary	Education
20	$0.06	62	F	House	2	11yrs	<$70k	Tertiary	Retired
21	$0.06	68	M	House	2	8yrs	<$70k	Secondary	Self-employed
22	$0.06	35	M	House	4	9yrs	>$70k	Secondary	Trade

Of the 22 participants interview for this study, 12 person were identified as being over 60 years old with nine female participants and 13 male. Table 5.2 above provides a summary of the profile of the participants in this study. Participants were divided into two cohorts based on the level of FiT they receive. The $0.44 cohort (12 persons) acquired solar PV during the period 2008-2012 when solar FiTs in south east Queensland were $0.44 for each kilowatt hour of power exported back to the grid. The $0.06 cohort (10 persons) acquired solar PV after July 2012 at which time government incentives and solar FiTs were being reduced or concluded.

Data Collection

The first section of the interview was a general discussion about the participant's decision making when acquiring goods or services. The purpose of this was to understand the usual motivators of purchase decisions for general goods and services to contextualize the discussion on acquisition and use of solar PV. Interviews were open-ended and semi-structured and participants were asked what important considerations they used when making purchasing decisions. The type of typical questions asked were: "When you are choosing a product of service, what are the features that you consider most important?"; "What things do you look for, when you are purchasing a product?" Prompts included what they looked for in products such as white goods or motor vehicles. The type of prompts included: "If you were going to go and buy a new fridge today, what would be the features you would look for?" Additional prompts included asking what they looked for in day-to-day products such as groceries.

In the second part of the interview, participants were asked about the issues that led them to acquire solar PVs; the acquisition process; and the results of the acquisition. Participants were asked: what motivated them to acquire solar PV; the information they relied upon to make this decision; their confidence and trust in the information; and whether the acquisition of solar PV resulted in any behavioral change. Typical questions included: "What motivated you to get a solar unit?; When you went to go and buy it, where did you get your information from?; Did you change behaviour?" At the conclusion, a brief demographic survey was undertaken to obtain key socio-economic information.

The interviews were audio-recorded and transcribed verbatim. The data were explored and coded manually after the transcripts were read and re-read to identify common and contrasting concepts. Thematic analysis involves a process of data immersion and interpretation, meaning transcripts are read and re-read and then coded into common categories, themes and patterns (Wrapson & Devine-Wright, 2014). The data was manually coded into categories and concepts that emerged from the data. Critically, these have been summarised in tables reflecting each cohort providing insight into the thematic structures, as the results reference multiple excerpts from the raw data. These tables allowed the anonymity of participants to be protected through the use of a numeric identifier that summarised the demographic details of the participant in a non-identifiable format.

Results

Data gathered from the interviews revealed that there were similarities and differences between the two cohorts of participants (those who receive \$0.44 per Kw and those who receive \$0.06 per Kw) in terms of their motivations for installing solar PV and their use of electricity after installation. There are four main themes that emerge from the data. Three of the main themes explain why the participants installed solar PV (Economic, Social and Environmental motivations) and the fourth relates to participants' use of electricity after installation (Behavioral change). The differences and similarities that emerged from the data are captured below under these main themes.

Economic motivators

Economic motivators was the strongest of the themes with the most frequent economic response from participants for acquiring solar PV (summarised in Table 5.3) being a perception of increasing electricity prices. This response was provided by all but one of the \$0.44 cohort and by all but one of the \$0.06 cohort. Participants such as P03 said they decided to acquire solar PV to:

> "*save on my electricity bill*". (P03)

Table 5.3 Summary of solar PV economic responses

Theme	**\$0.44**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**
Feed-in tariff (FiT)		x	x	x	x	x	x		x	x	x	x	x
Power bills/electricity price		x	x	x	x	x		x	x	x	x	x	x
Payback period				x		x	x						
Good investment		x		x		x			x			x	x
Quality of products/brand		x	x				x						
	\$0.06	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**		
Feed-in tariff (FiT)		x											
Power bills/electricity price			x	x	x	x	x	x	x	x	x		
Payback period			x		x								
Good investment		x	x		x		x	x		x	x		
Quality of products/brand			x	x		x	x	x			x		

In addition to costs being a prominent theme, participants from the $0.44 cohort also indicated they were motivated by the economic benefits from FiTs with only one participant not indicating it as being important in their decision to acquire solar PV. The $0.44 FiT was identified by some participants as:

> "*too good to pass up*" (P12); and

> "*I just couldn't resist the stupidity of being paid 44 cents for something that I was going to be charged 28 cents for*" (P02).

The reverse was the case for the $0.06 cohort with only one participant saying the solar FiT was a feature in their decision to install solar PV:

> "*it would have been nice to get the $0.44 but the FiT we receive helps to keep our bills down*" (P13).

Social motivators

Information channels emerged as a major social theme with most participants indicating they felt they had adequate information prior to acquiring solar PV, which are summarised in Table 5.4.

Table 5.4 Summary of solar PV social responses

Theme	$0.44	01	02	03	04	05	06	07	08	09	10	11	12
Adequate information		x	x	x	x		x	x	x	x	x	x	x
Inadequate information						x							
Influence from family/friends					x	x		x	x				
Influence of marketing/advertising									x	x			
Purchased from energy provider						x		x	x		x		
	$0.06	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**		
Adequate information		x	x	x		x	x	x	x	x	x		
Inadequate information					x								
Influence from family/friends				x	x		x		x				
Influence of marketing/advertising													
Purchased from energy provider					x	x							

When asked about where they got their information from, many indicated they had done various levels of research prior to reaching a decision, several indicated their decision was based on informal channels such as family and friends and only two indicated their purchase decision was based on marketing or advertising:

> "*It came in a letter, I think. That's how I first knew about it*" (P08).

Only two participants, one from each cohort, indicated they had inadequate information at the time they acquired solar PV, but still went ahead with the acquisition. An important context for responses on the adequacy of information was the information source. A number of participants indicated they received their information from energy providers which were large companies that had been around for several decades and they believed they could have any problems rectified into the future. Six of the 22 participants (Table 5.4) also said they acquired their solar PV from their energy provider based on the information they received:

> "*I felt it was worth taking the risk and doing it. I didn't feel that I could lose anything by it*" (P07); and

> "*Well, I got it through (company), mainly, because I reckon in 20 years' time (company) will still be there*" (P10).

Environmental motivations

Of the motivators, environmental issues were the least discussed and was the only theme in which some of the participants mentioned nothing. Some participants indicated they believe in using alternative energy and/or that their decision to acquire solar PV was good for the environment (Table 5.5).

Table 5.5 Summary of solar PV environmental responses

Theme	$0.44	01	02	03	04	05	06	07	08	09	10	11	12
Good for environment		x	x	x	x		x	x		x	x		
Belief in alternative energy				x	x							x	
	$0.06	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**		
Good for environment		x		x	x	x		x			x		
Belief in alternative energy								x					

Some participants acknowledged that they were disinterested in environmental issues -:

> *"Never think about that* [the environment]*"* (P08).

However, most participants recognised the value to the environment of solar power with comments such as:

> *"Well, my partner, she's very conscious as far as the environment is concerned. She's had me leaning that way, too. But I'm not near as dedicated as she is"* (P09); and

> *"Energy efficiency is something that is paramount in making stuff these days"* (P13).

Behavioural change

The biggest difference between the two cohorts was behavioural change and Table 5.6 summarizes the responses from both cohorts across this theme. Participants were asked whether the acquisition of solar PV resulted in any changes of behaviour. The purpose of this was to test the environmental effectiveness of the solar PV FiTs under different policy settings.

Table 5.6 Change as a result of solar PV

Theme	$0.44	01	02	03	04	05	06	07	08	09	10	11	12
No change in behaviour			x			x			x			x	x
Changed behaviour		x		x	x		x	x		x			
Financial return from FiT		x		x	x	x			x	x	x	x	x
Improved quality of life		x											
	$0.06	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**		
No change in behaviour													
Changed behaviour		x	x	x	x	x	x	x	x	x	x		
Financial return from FiT													
Improved quality of life		x											

One-half of the $0.44 FiT participants indicated they had changed their behaviour after acquiring solar PV whereas all of the 0.06 FiT participants indicated they had changed their behaviour after acquiring solar PV. The responses from the participants provide further insight into the type of behavioural change. Four of the participants receiving the $0.44 FiT indicated they were motivated to acquire solar PV based on the financial return from the FiT and changed their behaviour as a result:

> "*It sounded good that I could save some money; that I could get some money*" (P08);

> "(It was) *too good to pass up and also just thinking about paying the bills in the future*"(P10)

In order to maximise the financial returns from the $0.44 FiT, a number of participants from this cohort indicated they changed their behaviour. Using electricity during the day was most likely to reduce the returns from the solar FiT and recognising this, participants changed their behaviour accordingly as indicated by the following responses:

> "*Definitely. We have obviously tried to reduce our use during the solar generation hours because of the 44 cent feed-in*" (P04);

> "*Change in behaviour, definitely. But not hard and fast. I didn't enforce it with the family*" (P03);

> "*What I said to my wife around the fact that it was a feed-in tariff and as such, if you want to maximise its payback, you want to minimise your consumption through the day*" (P06)

> "*I put my dishwasher on at night, if I think about it*" (P08); and

“*Well, I wash first thing in the morning, 5 o'clock or so in the morning; and I do the ironing at that time of the morning, too”* (P10).

All of the 10 participants receiving the lesser $0.06 FiT indicated they had changed their behaviour since acquiring solar PV. Most of them indicated the behavioural change was to optimise use of electricity generated by solar PV and to minimise the amount of electricity purchased from their energy supplier:

“*We are slightly more diligent in the fact that the pool pump is only on during the day. We use the dishwasher, washing machine and dryer as much as we can just during the day*”. P17; and

“*We will try to make sure the washing machine goes on when the solar is operating. So we use that rather than pay 28 cents*.”P20

Discussion

This study explored the lived experiences of 22 persons who acquired solar PV under two different FiT policy settings. The major variable that separated each group was the FiT each received. The study examines their experiences and motivations to acquire solar PV and their energy consumption behaviour before and after solar PV acquisition. The qualitative approach undertaken in this study allows for a broad examination of motivators of behaviour and how these may translate to the purchase and use of renewable energy technology. The responses from participants in this study indicate that social and economic factors were more important than environmental factors in their decision to acquire solar PV.

This study identified that participants from both cohorts changed their behaviour to optimise the benefits from solar PV. The types of behaviour change expressed by participants may potentially provide different outcomes for policy development. Participants from the $0.44 cohort changed their behaviour by minimising use of power during the day to optimise financial returns from the FiT. Previous literature has identified that this type of behaviour is most likely to increase demand for electricity during peak periods and increase supply of electricity during off-peak periods (Nelson et al., 2012). Participants in the $0.06 cohort received the $0.06 FiT for surplus electricity they sell to their energy supplier whilst it costs them $0.26 to $0.29 for electricity purchased from their energy supplier. The majority of this cohort indicated they changed their behaviour to utilise electricity from solar PV to minimise demand for energy from the electricity grid. They indicated they used self-generated power during the day for household activities which enabled them to reduce consumption at times when they would be using power from the grid.

Previous research acknowledged the consumer decision to acquire a solar PV system is complex requiring information that many average consumers are unlikely to have (Guidolin & Mortarino, 2010). These previous studies also identified that households with higher levels of education and in higher skilled occupations were more likely to find it easier to access information on residential solar PV systems (Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011; Nelson et al., 2011). The participants in this study from both cohorts had diverse backgrounds, levels of education, financial resources and life experiences yet most said they independently acquired the information needed to make a decision to acquire solar PV.

In this study it was the perception and concern of increasing electricity prices that was the most significant motivator to investigate and install solar PV. This decision to adopt solar PV continued after incentives such as solar FiTs had been significantly reduced (Table 5.1). Whilst the uptake in solar under higher FiTs may validate policy focussed on developing the solar PV industry, past research has raised questions about the social, economic and environmental benefits. The uptake of solar PV under the lower FiTs, seen in conjunction with the expressed behaviour outlined in this study, would indicate greater use of solar PV to reduce reliance on electricity from carbon-based generation. In this study, all of the $0.06 FiT participants indicated they changed their electricity consumption behaviour to optimise electricity generated by solar PV thereby minimising the cost of their household electricity consumption from the grid. This is an important contribution from this study for policy makers seeking to reduce reliance on GHG producing sources of electricity going forward.

The rapid uptake of solar PV technology by consumers has not only transformed the electricity market in terms of demand and supply, but also means that understanding consumer behaviour will be critical to ensuring future solar PV policies achieve their objectives and unintended consequences identified in past research are minimised. The responses from the participants in this study provide guidance for further research based on before and after acquisition of solar PV. This would allow for policy makers to test whether consumption of electricity from the grid from different cohorts of solar PV customers could be quantified and how this use may impact on the future design of solar PV policies.

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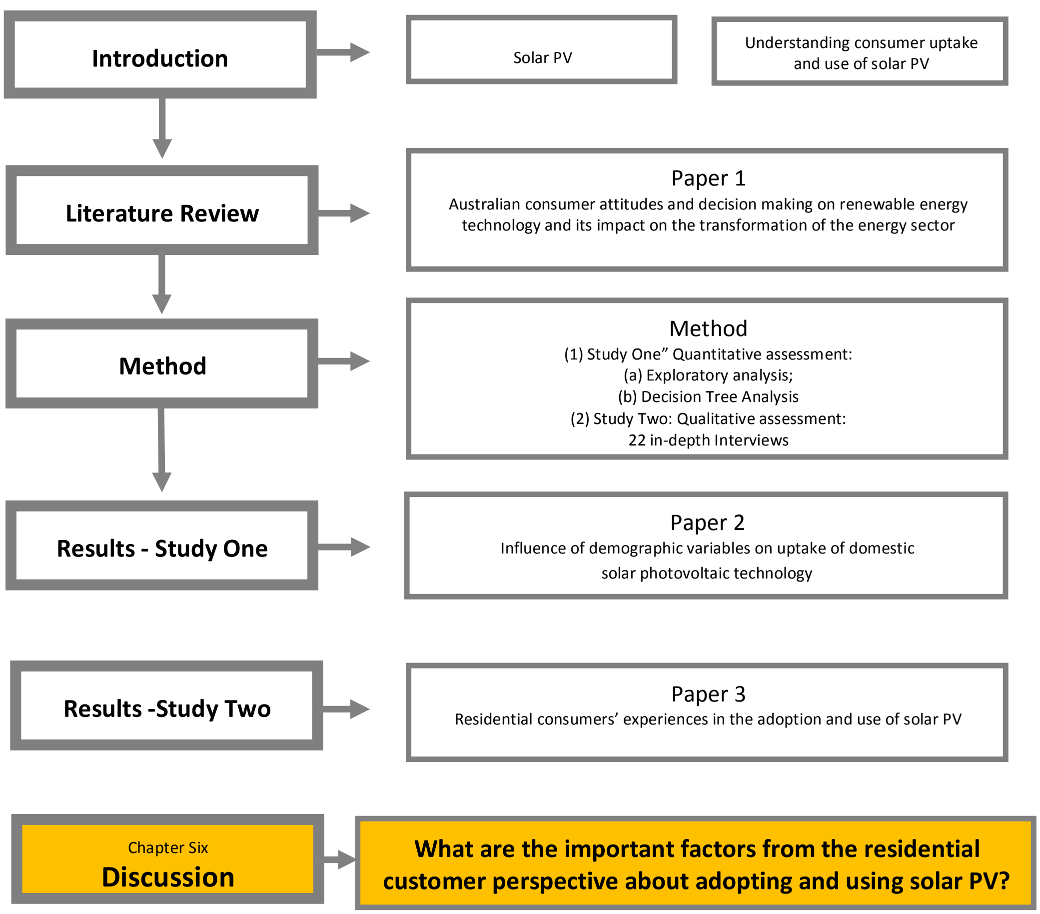
6

Chapter 6: Discussion

What are the important factors from the residential customer perspective about adopting and using solar PV?

Figure 7.1 Relationship between this chapter and thesis



Overview

If the purpose of domestic household solar PV policies is to reduce demand for electricity from GHG producing sources, it would seem reasonable to examine the effectiveness of such policies to ensure they are achieving the stated objectives. Domestic solar PV policies based around solar FiTs have been undoubtedly successful with the cumulative installed capacity of solar PV units increasing by 100-fold from nearly 10MW to more than 1000MW in the four years from 2007 to 2011 (Nelson, Simshauser & Nelson, 2012). This is especially evident in Queensland, which has almost one-third of all PV capacity in Australia (Flannery & Sahajwalla, 2013; Chapman et al., 2016). Table 6.1 shows that before the introduction of FiTs in Queensland, there were just 533 installed systems.

Table 6.1. Domestic solar PV south east Queensland 2008 to 2014

Installation year	Solar PV systems	%
As at July 2008	533	0.04%
As at July 2009	5947	0.49%
As at July 2010	27,100	2.2%
As at July 2011	83,188	6.9%
As at July 2012	157,849	13.1%
As at July 2013	229,439	19.1%
As at July 2014	264,807	22.1%

Source: Energex 2015, ABS 2014

To achieve the surge in uptake of solar PV as shown in Table 6.1 above, governments have provided a range of incentives such as solar FiTs; this thesis has sought to contribute an assessment of the effectiveness of these policies to guide the development of future policy. This research has explored, through two studies (a quantitative study and qualitative study), the profile and experiences of residential customers who have installed and used solar PV. The three papers presented in this thesis add to the body of knowledge related to the effectiveness of alternative energy policies, and policies seeking to reduce GHG emissions. The following discussion brings together the results from these papers to summarise the key findings and theoretical perspective of this thesis. The contribution of this research to knowledge and practice in the field is discussed, as are the strengths and limitations of the research, with opportunities for future research outlined.

Response to research question – the profile and experience of residential customers who decide to adopt and use solar PV

The purpose of this thesis was to elucidate the profile of consumers who acquired solar PV under different policy settings, and, from a customer perspective, whether the acquisition of this technology prompted changes in consumer behaviour with respect to energy use. The findings from the two studies undertaken to address the purpose of this thesis are synthesised according to the sub-questions posed in Chapter One.

What is the profile of customers of domestic rooftop solar PV in south east Queensland?

An important contribution of this research is that it has contextualised previous solar PV research with the current profile of technological adoption. The description of consumers, derived from the literature as being educated and economically successful (Paper One), is different to the current profile of consumers identified by the quantitative analysis for this thesis (Paper Two: Tables 4.9 and Figure 4.4). The difference between these two profiles can be resolved through the lens of Diffusion of Innovation Theory (Rogers, 2003), which illuminates this phenomenon. Table 6.2 (below) outlines the characteristics of each of the categories of Diffusion of Innovation Theory.

Table 6.2. Diffusion of Innovation Theory categories and characteristics

Category	Percentage	Characteristics
Innovators	2.5%	Venturesome: financially capable; educated; accept uncertainty; like gadgets
Early Adopters	13.5%	Respectable: higher socio-economic; well-informed; fashion conscious; change agents
Early majority	34%	Deliberate: cost sensitive; risk averse; off-the-shelf technology; rapid payback periods
Late majority	34%	Skeptical: practical; conformity rather than product benefits; economic necessity
Laggards	16%	Traditional; suspicious; limited resources; high levels of control over where and when to adopt new technology

Adapted from: Rogers, 2003; Robinson. 2009)

The correlation of solar PV uptake from Table 6.1 to the categories and characteristics summarised in Table 6.2 allows for previous research and these current studies to be contextualised. Prior to July 2008, Table 6.1 indicates that 533 households, or approximately 0.04% of the 1.198 million dwellings in south east Queensland, had acquired solar PV. Translating this to Diffusion of Innovation Theory this 0.04% of the population would be categorised as 'innovators', based on Table 6.2. Similarly, the uptake in solar PV from July 2008 to July 2012 (Figure 6.1) represents 13.1% of the population of south east Queensland, a group that would be categorised as 'early adopters' based on Diffusion of Innovation Theory.

As discussed above, the data in Table 6.1 can be used to correlate solar PV uptake in south east Queensland with the categories in Diffusion of Innovation Theory. In addition, the examination of the literature (Paper One) in conjunction with the quantitative study (Paper Two) allows for the explanatory variables that describe solar PV consumers at different times to be contextualised to Diffusion of Innovation Theory. Solar PV consumers are described in the literature as being better educated and more financially capable (Paper One). As most of this literature was based on research prior to 2012, such a description of solar PV consumers would be based on the levels of solar PV uptake in Table 6.1, which indicates these consumers would be innovators or early adopters.

However, the description of the solar PV consumers derived from Study One (Paper Two) identifies very different characteristics, as these include solar PV uptake to July 2014. Paper Two reports that education and financial capacity did not appear to be as significant as identified in previous literature, and found explanatory variables such as the number of bedrooms, type of dwelling, being aged over 55 years old, and family composition of a household as being significant. Table 4.9 highlights the five most significant variables in each year and how these changed over time and under the different FiT policies. The number of bedrooms and level of education did not become a significant variable until the FiT was reduced to $0.06. This phenomenon was also identified in the predictive BRT analysis (Figure 4.4 [Chapter 4]). The differences between the profile of solar PV consumers in previous literature and the profile of solar PV consumers from Study One can be explained through the lens of Diffusion of Innovation Theory: both profiles provide a description of the consumers acquiring solar PV at that period of the technological adoption under investigation. The information obtained from Study One (Paper Two) helps to contextualise previous research (Paper One) and more significantly, provides a more nuanced profile on the most recent consumers of solar PV. Potential changes in the profile of consumers may impact on policy outcomes which Paper Three shows may have extraneous policy outcomes (negative and positive) for solar PV and general energy policies.

What are the inter-related factors that motivate consumers to acquire solar PV?

Previous research on solar PV or consumers of solar PV have tended to focus on only single policy outcomes such as environmental, economic or social attributes (Bahadori, 2013; Auger et al., 2010; Martin et al., 2012). Other researchers tended to focus on policy, policy-induced technical change, financial issues and consumer environmental attitudes (Gadenne et al., 2011; Peters et al., 2012; Negro et al., 2012) or consumer issues such as financial capacity, home ownership status and education (Byrnes et al., 2013; Grösche & Schröder, 2014; MacIntosh & Wilkinson, 2011). Study One (Paper Two), however, found the profile of solar PV customers as more complex with single explanatory variables not adequately explaining the phenomena of the profile of solar PV customers. The CART and BRT methods used in Study One identified linkages and inter-relationships between explanatory variables that had not been identified in previous research (Paper Two). This research provided a different profile of the solar PV adopter compared with previous research findings. As discussed above, the new explanatory variables included people aged over 55 years, family composition and type of dwelling as important and inter-related in describing solar PV consumers. The new knowledge about socio-economic influences from Study One provides greater contextual understanding of the phenomena of solar PV uptake.

What are the lived experiences of the people who acquired and are using solar PV and how do these lived experiences provide insight into understanding solar PV policy from the residential customer perspective?

The success of policies that encourage the uptake of renewable energy requires consumer acceptance and engagement with new technologies such as solar PV (Paper Three). Previous literature reviewed in Paper One identified only one study that was based on direct responses from consumers. This study by Hampton and Eckermann (2013) was based on qualitative workshops undertaken in 2005 and 2012, which examined knowledge and understanding of solar PV and renewable energy products. Hampton and Eckermann's (2013) study was focussed on better understanding of solar PV by consumers, rather than better understanding consumer adoption and use of solar PV, the focus of this thesis. Unlike any previous studies, this thesis is the examination of solar PV adoption and use under different policy settings and incentives (Paper Three). Study two sought to understand the adoption and use of solar PV under two very different policy settings (a $0.44 FiT and a $0.06 FiT) (Paper Three).

Electricity prices were identified as significant motivators to acquire solar PV, by the majority of participants across both policy settings. However, it was the financial return expressed by the $0.44 cohort that was a unique motivator of solar PV acquisition for that group (Article Three). This motivator also appears to have led to expressed behaviour that saw this group minimise use of solar PV during daylight hours to maximise returns from the solar FiT. The reverse was the case for the $0.06 cohort, who were not motivated by financial return and endeavoured to use electricity generated from solar PV during daylight hours to offset electricity costs. This research showed two different types of behavioural change expressed by participants under different policy settings that would provide different outcomes for solar PV policy. The behavioural responses from the $0.44 cohort would indicate a shift in electricity consumption to non-solar generating times, which is more likely to impact on electricity demand at peak periods (Nelson et al., 2012). Meeting peak electricity demand is a major driver of building future electricity transmission infrastructure (Byrnes et al., 2013). The behavioural responses from the $0.06 cohort would indicate a shift in electricity consumption to use of electricity generated by solar PV, thereby reducing reliance on electricity provided by the grid.

One of the overarching objectives of solar PV policy has been to increase the amount of solar electricity to reduce reliance on GHG producing sources (Byrnes et al., 2013; Grösche & Schröder, 2014; MacIntosh & Wilkinson, 2011; Nelson et al., 2012). This research has found that the level of FiT can encourage behaviour that fulfils or undermines policy objectives of greater utilisation of solar PV produced electricity.

Research significance

A major significance of this research is the combination of an innovative quantitative method and a further qualitative examination of consumer adoption and use of solar PV technology that is transforming the energy sector. This thesis employed complementary quantitative analysis to seek to understand social dimensions of consumer adoption of solar PV. This is the first time CART and BRT methods have been employed to investigate this complex statistical problem. The triangulation of the socio-economic (explanatory variables) from the quantitative data, using different analytical methods, enables the development of a comprehensive profile of solar PV consumers and the examination of whether these explanatory variables are inter-related. The new knowledge from this research is gained from the examination of the inter-relationship between explanatory variables that may influence a consumer to acquire solar PV under different policy settings (Paper Two). Utilising these different analytical methodologies, this study was able to investigate the profile of solar PV consumers and how this profile may change over time and under different policy settings. Despite the awareness of the general importance of socio-economic explanatory variables that have arisen from previous reviews of solar PV policy, there remains a knowledge gap about the individual and combined impact of these variables and how these inter-relate to the objectives of solar PV policies. Paper Two provides an important contribution towards advancing the knowledge of explanatory variables of consumer adoption of solar PV.

The other significant contribution of this thesis is the qualitative examination of solar PV adopters and users and how they acquired and used solar PV under different policy settings (Paper Three). Previous literature has not identified any similar studies examining solar PV or consumers of solar PV under circumstances of changing policies and incentives. By looking at solar PV consumers adoption and use under different policy settings, this thesis was able to explore the consumer experience with solar PV. Based on this study (Paper Three), previously unexplored themes of motivation and behavioural change in relation to the use of solar PV technology were identified. The practical significance of this research is that it has shown distinctly diverse types of behavioural change acknowledged by participants under different policy settings that provide contradictory outcomes for solar PV policy. This thesis makes an important contribution towards informing the development and future design of more effective domestic solar PV policies.

This research is significant because it provides a greater depth of understanding to the topic of consumer adoption and use of solar PV. It achieves this through a rigorous and innovative quantitative research method that demonstrates that the consumer’s decision to acquire solar PV is complex and multi-dimensional. This is further refined with the use of qualitative research that gives a voice to consumers on this topic, which has been mostly silent in previous research.

Policy significance

Developing policies that encourage residential consumers to utilise solar PV and reduce GHG emissions is of practical importance and has long term economic, social and environmental benefits. To maximise the implementation of these policies, the role of the consumer is critical as the use of solar PV technology may, or may not, align with policy objectives of the energy professionals (DeCicco et al, 2015). The research and analysis of consumers and their interaction with solar PV policy is important in assessing policy outcomes and how the policy can be delivered or adapted (Greene, 2013). The new knowledge derived from the two studies undertaken provides important context to previous research and insight into future policy development.

Strengths and limitations of this research

This research is both pertinent and timely. The study is grounded in local reality and is particularly timely given increased policy emphasis on solar PV. The strength of this thesis is that it draws on two separate studies to answer the research question. Firstly, this thesis set out to examine the contemporary profile of consumer adoption and use of solar PV based on a specific area (south east Queensland), which has one of the largest penetrations of domestic rooftop solar PV in the world. In addition, previous research was found to be based on a different segment of innovation adoption, which has since changed due to the surge in uptake of solar PV. This is an important contribution of this research, as it contextualises previous solar PV research with the current profile of technological adoption.

The other major differentiation between the study in this thesis and other research is that it explores consumer adoption and use of solar PV across different solar FiT policy settings, which have not been undertaken in other research. Many of the past examinations of solar PV policy have examined solar PV and consumers at a national or regional level. This previous research identified key variables that may have been influential in solar PV acquisition, but it did not examine the significance or inter-relationship between these variables and how these may have changed over time and under different policy settings. No previous studies have been identified that examined different solar FiT policy settings.

This thesis adds to the body of literature on solar PV adoption and use by consumers. Most of the previous research on consumers and consumer behaviour has been based on secondary data, with much of this data at the national or international scale with any consumer issues extrapolated from these secondary sources. Only a small number of researchers have undertaken primary research based on the responses of individual consumers. Whilst the phenomena relating to consumer energy was a key research focus of previous research, researchers did not explain the motivation or context of consumers who adopted or did not adopt renewable technology. The key feature of this research is that it is centred on people. The quantitative study explored the inter-related explanatory variables of the people that acquired solar PV. The qualitative study then used participants' own words to explore their motivations to acquire and use solar PV. Further research based on before and after acquisition of solar PV would allow policy makers to test whether consumption of electricity from the grid from different cohorts of solar PV customers could be quantified and how this use may impact on the future design of solar PV policies.

A major strength of this research is that it used complementary quantitative analysis to triangulate and understand social dimensions of the problem. As discussed above, this was the first time CART and BRT methods have been employed to examine data related to consumer adoption of solar PV. However, the findings from the data should not be generalised to jurisdictions outside south east Queensland. The methodology used may provide a guide to other researchers using statistical data to further explore socio-economic trends in the uptake of solar PV.

A limitation of the quantitative study was the requirement to use postal areas as the source of data in Study One. The scale of the information in a postal area is such that it does not capture the individual socio-economic profile of each consumer acquiring solar PV, but rather it produces a general overview of the economic and social resources of the postal area in which they live (Macintosh et al., 2011). Data at a smaller scale was not available publicly because it may identify individual persons. To overcome this limitation, the quantitative analysis utilised different methodologies to examine the data and triangulate and cross verify the results and subsequent analysis.

Another limitation of the qualitative study was it was based on small non-random samples of persons living within south east Queensland. Notwithstanding this, this study provided insight into the lived experience of these persons regarding their day-to-day acquisition of goods and services, their motivations to acquire solar PV and their subsequent behaviour after acquisition. The strength of the qualitative analysis was it examined two different cohorts of persons who acquired solar PV during different FiT policy settings. This enabled themes on behavioural change to be explored. In addition, the method used for the qualitative analysis enabled the attitudes of participants to be examined on day-to-day acquisitions of goods and services and also to examine this against their decision to acquire solar PV.

Conclusion

Whilst published literature contains significant research regarding technical aspects of solar PV adoption, the scope of research examining the consumer's perspective and interaction with solar PV has been limited. Previous studies have frequently only dealt with individual aspects or variables related to consumers rather than the complex system of issues and variables that constitute consumer decision making and behaviour. This is particularly topical in the context of Australia which was been prominent in the adoption of solar PV technology and where only one published Australian study of consumers was identified based on original research. This thesis therefore makes a significant contribution through original research to the knowledge and understanding of consumer adoption and use of solar PV and renewable energy products.

Comment [U1]: impact on or constitute????

For policy makers, the findings from this research indicate the important linkages between demographic explanatory variables in solar PV uptake. This was obtained through the synthesis of previous literature which identified that single variables were mostly used to describe the phenomena of solar PV uptake. Whilst single variable descriptions such as financial capacity or level of education may have been relevant to the early stages of the adoption of solar PV technology, this project has shown these may be less reliable in the latter stages of adoption where the motivations of consumers are more nuanced. The significance of this research is the use of multiple data sources for the same area over time to map the phenomena of solar PV uptake. It then applied different quantitative methods to interrogate and triangulate the data (particularly Classification and Regression Tree (CART) and Boosted Regression Tree (BRT)), which enabled cross-verification for analysis and deduction. This is the first time CART and BRT methods have been employed to investigate this complex statistical problem. As a result, the analysis showed that the explanatory variables, that describe the profile of solar PV adopters, are complex and inter-connected and that these variables changed under different policy settings. This insight will be important in the future development and analysis of solar PV policy.

This thesis also examined consumer interaction with two different solar policies from 2010 to 2014 and identified a number of issues of significance raised by consumers that could impact upon the objectives of solar PV policies. The objective of solar policies between July 2008 and July 2012 was to encourage the uptake of solar PV, based on a $0.44 FiT. The level of FiT was based on the policy premise that the resultant uptake and use of solar PV would reduce demand for electricity from GHG producing sources of energy and it would encourage the growth of the solar PV industry (Byrnes et al., 2013; MacIntosh et al., 2011). The research for this thesis found that many of the participants receiving the $0.44 FiT advised they changed their behaviour to optimise revenue from solar PV rather than use solar PV to reduce energy from GHG producing sources of energy. This should be further examined to quantify potential negative consequences on overall energy policy, and in particular policy designed to manage peak demand.

Conversely, participants receiving the $0.06 FiT paid after July 2012 indicated they changed their behaviour in a way to optimise use of solar PV and reduce their reliance on GHG producing sources of energy. This should also be further examined to quantify any potential positive impact on general energy policy aimed at increasing the use of solar PV to reduce demand for electricity during peak demand and from sources that produce greenhouse gases. The differences in behavioural change based on the two different policy settings is significant as it identifies positive and negative consequences flowing from policy settings.

The combination of the two studies in this thesis provides a more nuanced and comprehensive understanding of the profile of the consumers who adopted and used solar PV under the different policy settings in south east Queensland. This thesis shows the profile of solar PV consumers has evolved and should be continuously reviewed to capture the changing demographic profile of solar PV consumers. In addition, any such profile of consumers should be cross-verified through different analytical methods such as those described by this thesis.

Whilst quantitative approach methods, such as those used for this thesis, can provide illumination of changing demographic variables and potential inter-relationships between such variables, the contribution from this thesis to solar PV policy is the integration of qualitative methods with the quantitative to further examine the phenomena based on the lived experiences of individual consumers. It is from this mixed-method approach that this thesis identifies that future policy should be based on a profile of consumers that is complex and continuously changing and how the adoption and usage of solar PV by consumers may significantly impact on policy outcomes.

In conclusion, this thesis has shown that to maximise the benefits from policies that encourage solar PV, the role of the consumer is critical as their use of renewable energy technology may, or may not, align with policy objectives of the energy professionals. The contribution of this research is that it provides a better understanding of consumer interaction with solar PV technology. From this understanding, policy options can be developed and/or adapted to address technical and/or human-related issues that impact on the effectiveness of solar PV policy aimed at reducing peak demand and creating low carbon communities.

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Appendix: A

Thesis context – personal case study

Beliefs, values and assumptions

It was a change in personal circumstances in December 2013 that helped guide the question for this thesis. Prior to December 2013 I lived in an apartment complex that was unable to facilitate individual solar PV. The electricity consumption for the ten years of living in the apartment was fixed due to the type of dwelling and fluctuation of the seasons. A lack of sustainable design (Buys et al., 2012) by the developers of the apartment complex resulted in the need for air-conditioning during hotter months and restricted internal spaces such as the kitchen limited the type of appliances that may have been more energy efficient.

The new dwelling, a four bedroom house with a swimming pool (Figure A1), presented a number of opportunities to improve its energy efficiency and reduce electricity consumption. These included upgrading fixed electrical appliances that were aged more than 10 years old such as air-conditioners and the pool pump. The first electricity bill after moving into a house highlighted potential long term economic benefits from solar PV which was a major motivator for its acquisition. Below is a personal case study of my individual circumstances which outlines the rational for making a decision to acquire rooftop solar PV and the subsequent consequences of this decision. As a result I became aware of the linkages between solar PV, energy efficiency and behavioural change.

Figure A1: The new residence with in-ground pool

Case study context

The household in this case study is located in South East Queensland in that consisting of:

- two adults working from home;
- a 12 year old single storey four bedroom brick veneer house;
- an in-ground swimming pool;
- an off-peak electric hot water system; and
- a gas cooktop and electric oven.

The above details were identified as these variables may impact on translation of this case study to other households. A research report prepared by ACIL Allen Consulting for the Australian Energy Regulator (Table A1 below) shows the daily average consumption of 17kWh's for a household of two people with a pool and gas connection.

Table A1: Typical electricity use of Queensland household by size, swimming pool and gas connection - kWh per annum

Season	Household Size				
	1 person	2 person	3 person	4 person	5 person
Summer	1322	1858	2239	2899	2112
Autumn	1034	1566	1785	2357	1698
Winter	948	1391	1711	2172	1579
Spring	1055	1444	1937	2467	1735
Total usage	**4359**	**6259**	**7672**	**9895**	**7124**
Cost @ $0.250	$1089.75	$1564.75	$1918.00	$2473.75	$1781.00
Cost @ $0.275	$1198.72	$1721.22	$2109.80	$2721.12	$1959.10
Cost @ $0.300	$1307.70	$1877.70	$2301.60	$2968.50	$2137.2

Source: Acil Allen Consulting, 2014. (edited) Above costs are based on peak usage tariff only

Prior to any changes to the home, upgrade of appliances, or behavioral change the receipt of the first electricity bill in the new home for the period Dec 2013 to Feb 2014 showed an average daily usage of 36.22kWh. This bill was for a period of 68 days and consisted of 2165kWh @ $0.2673 for household electricity and 298kWh @ $0.12376 for off-peak hot water – a total of $677.11 (including GST). The daily household electricity consumption of 31.8kWh cost $9.35 and the off-peak hot water cost $0.59 per day. These figures indicated our household was using 50 per cent more power than the average Queensland household (Acil Allen Consulting, 2014) and was projected to use an average of 25kw per day at an annual cost of $2546.78.

An energy audit of the home found that it had air-conditioners that were more than 10 years old and an ageing pool pump that was not connected to any off-peak options and needed to run for between 8-10 hours per day. This resulted in the acquisition of new energy efficient air-conditioners and upgrading the pool pump which only required operating for between 4-6 hours per day. One of the motivational assumptions to investigate acquiring solar PV was based on historical trends of electricity prices which in the four years from 2009 to 2013 increased on average by around 59 per cent (ABS, 2013). A further assumption was that because the occupants were working from home during the day there was a potential for solar PV to reduce energy costs by producing what was mostly used during the day, with some surplus exported to the grid. Research into solar cells and inverters was based on tests undertaken by Photon Magazine which compared solar cells and inverters (http://www.photon.info/). This guided the final decision to acquire a 5kW SMA inverter (Figure A2) and 20 Seraphium 250W solar cells (Figure A3). The total final installed price was $11,789. However, after the Commonwealth Government Photovoltaic Rebate Program (PVRP), the final price was $7875. Based on an average payback period over ten years the solar system needed to save $787.50 per year.

Figure A2: Selected 5kW SMA inverter model

Figure A3: Selected Seraphium 250W solar cells

Case study results

Prior to acquisition of solar PV, the household was projected to use an average of 25kw per day compared to a similar household consumption of 17kWh (Acil Allen Consulting, 2014). The acquisition of solar PV was done in conjunction with acquiring energy efficient appliances that included air-conditioners, pool pump, dishwasher and household refrigeration. Table A2 shows the performance of the solar PV and the household energy consumption for the period 1 July 2014 to 30 June 2015. These figures show a daily decrease in energy use of 5.89kWh based on the original projected average daily use of 25kw per day

Table A2: Solar PV performance July 2014 to June 2015

	Units	Daily Units
Total energy produced	7.944Mwh	21.76kWh
Export solar PV to Grid	3.974Mwh	10.88kWh
Household solar PV energy use	3.970 Mwh	10.87kWh
Household energy use from grid *	3.006Mwh	8.23kWh
Total Household energy use	6.976Mwh	19.11kWh

* excludes hot water

The figures in Table A3 show that electricity purchased from the grid decreased from a projected average daily use of 25kw per day to 8.23kw per day. Following the acquisition of solar PV, the household engaged in behavioral change to optimize the use of solar PV and reduce use of grid supplied electricity. The figures in Table 2.3 show the composition of the daily decrease in energy use which comprises 10.87 kWh of self-generated solar PV electricity and 5.89kWh from energy efficiency and behavioral change. The annual value of self-generated solar PV electricity saved $1071.90 in energy costs which would have otherwise been purchased from the grid. The annual value of energy efficiency and behavioral change was $580.23. The annual value of solar PV electricity exported to the grid was valued at $238.44.

Table A3: Cost of energy sources July 2014 to June 2015

	Units	Unit Value	Price
Export solar PV to Grid	3.974Mwh	$0.06 per kWh	$238.44
Household solar PV energy use	3.970Mwh	$0.27 per kWh	$1071.90
Household energy use from grid *	3.006Mwh	$0.27 per kWh	$811.62
Household energy reduction (savings)	2.149Mwh	$0.27 per kWh	$580.23

* excludes hot water

The above figures are based on the assumption that energy efficiency measures which resulted in an additional cost of $5500 were offset by the household energy reduction of $580.23 per annum (Table 2.3). The payback period of 10 years identified previously required that the solar system needed to provide savings on electricity costs of $787.50 per year. The combined value of monies made from exporting electricity to the grid (238.44) and savings from household use of solar PV ($1071.90) resulted in a net value $1310.34 per annum attributable to the decision to acquire solar PV. This is the equivalent of a payback period of six years on the original cost of the solar PV system.

Case Study discussion

During the period from 2008 to July 2012, the then Queensland Government had policies that paid $0.44 FiT to domestic consumers who acquired solar PV. The level of this FiT was justified based on the financial payback period necessary to offset the capital costs of solar PV. As the capital cost of solar technology decreased in recent years and the solar industry matured the level of FiT was reduced to the current $0.06 based on advice from the Queensland Competition Authority (QCA, 2013).

The results from this case study confirmed the assumptions underpinning the decision of the household to acquire solar PV and FiT's were not the only way to incentivize households to acquire solar PV. Energy efficiency, behavioral change and self-producing energy which would otherwise have to be purchased from the grid have been shown to deliver economic benefits to households acquiring solar PV on reduced FiTs. Based on the results of this case study the research question of examining the differences between the attitudes and any behavioral change of persons who acquired solar PV during the period of $0.44 FiTs and the attitudes and any behavioral change of persons who acquired solar PV during the period of $0.06 FiTs.

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Appendix: B

Below is the full quantitative assessment undertaken for this thesis which was used for the development of Article Two.

Quantitative assessment

The quantitative assessment for this project used two different methodologies: a) a preliminary exploratory analysis which identified similarities, differences and gaps in the findings of previous literature, and; b) a decision tree analysis using statistical software to identify potential analysis bias from the exploratory analysis. The demographic data for this research was obtained from the Australian Bureau of Statistics (ABS) from the 2011 Census (ABS, 2013). The data on solar installation was obtained from the Australian Government Clean Energy Regulator (AGCER, 2014).

Exploratory analysis

A preliminary exploratory analysis was undertaken to compare the findings from the literature review to an actual demographic sample to identify similarities, differences and gaps. A series of tables were developed based on individual explanatory variables (Table B1) and solar PV uptake at annuals intervals from 2010 to 2014. The demographic data for the study areas was sub-divided into 115 postal areas (postcodes). This was the same scale of data collection used by AGCER for solar PV data. Each table of data was sorted based on the specific demographic explanatory variable and cohorts representing the upper, middle and bottom postcodes from the sample were then selected for analysis. The results were then examined against previous literature to identify any gaps or differences that would require further examination.

Table B1: Explanatory variables

Socio-economic variables	Definition (ABS)
People	Total number of persons in the postal area
Families	Two or more persons, one of whom is at least 15 years of age, who are related by blood, marriage (registered or de facto), adoption, step or fostering, and who are usually resident in the same household.
Income	Gross income from all sources
Education	Number of persons with a university or tertiary qualification
Over 55 years	Persons aged over 55 years old
Over 65 years	Persons aged over 65 years
Owners	Own a dwelling outright or with a mortgage
Renters	Renting a dwelling
Mortgage	Housing loan repayments being paid on a monthly basis by a household to purchase the dwelling
Rent	Dollar amount of rent paid by households on a weekly basis for the dwelling
Private homes	Number of all private dwellings
Houses	House which stands alone in its own grounds separated from other dwellings by at least half a metre
Units	Includes flats, units and apartments - dwellings that do not have their own private grounds and usually share a common entrance foyer or stairwell
Duplexes	Semi-detached dwelling including terrace house and townhouses - dwellings that have their own private grounds and no other dwelling above or below them
Three bedrooms or more	Occupied private dwellings with three or more bedrooms

Source: ABS Census Directory http://www.abs.gov.au/ausstats/abs@.nsf/0/4B6D4A6E729E8275CA25720900078321?opendocument accessed 13 March 2015

Previous research on the factors that influenced uptake of solar PV have asserted financial capacity as an important factor in solar PV uptake (Byrnes et al., 2013; Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011; Nelson et al., 2012). The exploratory analysis used five different demographic explanatory variables to examine the influence of financial capacity and solar PV uptake and these are shown in Tables B2, B3, B4, B5 and B6.

Table B2: Exploratory Analysis – Solar installations and Median Weekly Income

	Rank	Postcode	Median weekly income	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4069	$2,347	3.26%	6.58%	13.10%	19.68%	22.70%
	2	4065	$2,286	2.51%	4.41%	8.15%	12.87%	14.63%
	3	4156	$2,265	4.11%	8.54%	16.97%	29.82%	35.62%
	4	4154	$2,261	2.58%	6.95%	15.76%	26.59%	31.78%
	5	4155	$2,230	6.29%	10.57%	22.00%	37.14%	43.43%
Middle	55	4165	$1,478	5.06%	11.08%	19.46%	28.17%	32.36%
	56	4101	$1,475	1.27%	2.13%	3.83%	5.65%	6.25%
	57	4173	$1,474	2.98%	6.91%	13.95%	20.39%	23.88%
	58	4179	$1,465	4.07%	7.35%	13.78%	19.81%	22.38%
	59	4159	$1,462	5.65%	10.95%	19.44%	28.03%	31.97%
Bottom	113	4303	$855	1.88%	4.91%	10.48%	14.45%	16.47%
	114	4205	$848	3.90%	10.47%	22.27%	27.55%	31.40%
	115	4183	$801	2.04%	5.34%	9.43%	14.37%	15.90%
	116	4507	$747	4.34%	12.42%	21.01%	27.36%	30.34%
	117	4184	$598	7.88%	13.34%	19.54%	25.11%	27.52%

Table B3: Exploratory Analysis – Solar installations and monthly mortgage payments

	Rank	Postcode	Median weekly income	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4155	$3,200	6.29%	10.57%	22.00%	37.14%	43.43%
	2	4154	$2,600	2.58%	6.95%	15.76%	26.59%	31.78%
	3	4171	$2,600	1.19%	2.49%	5.32%	8.97%	10.41%
	4	4065	$2,500	2.51%	4.41%	8.15%	12.87%	14.63%
	5	4064	$2,500	1.52%	2.58%	4.79%	7.67%	8.60%
Middle	55	4055	$2,000	4.00%	8.55%	16.63%	25.44%	29.63%
	56	4112	$2,000	3.00%	10.08%	20.52%	29.88%	33.00%
	57	4035	$2,000	4.37%	8.82%	17.10%	26.55%	31.26%
	58	4119	$2,000	3.55%	8.99%	19.89%	30.42%	35.51%
	59	4109	$2,000	2.99%	8.24%	19.88%	27.66%	31.06%
Bottom	113	4034	$1,315	2.33%	5.04%	10.62%	16.40%	19.35%
	114	4303	$1,300	1.88%	4.91%	10.48%	14.45%	16.47%
	115	4183	$1,300	2.04%	5.34%	9.43%	14.37%	15.90%
	116	4184	$1,088	7.88%	13.34%	19.54%	25.11%	27.52%
	117	4008	$865	1.38%	3.45%	6.21%	11.03%	12.41%

Table B4: Exploratory Analysis – Solar installations and weekly rent

	Rank	Postcode	Median weekly income	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4000	$475	0.33%	0.54%	0.76%	1.15%	1.43%
	2	4154	$440	2.58%	6.95%	15.76%	26.59%	31.78%
	3	4069	$425	3.26%	6.58%	13.10%	19.68%	22.70%
	4	4006	$420	0.18%	0.37%	0.76%	1.24%	1.43%
	5	4156	$400	4.11%	8.54%	16.97%	29.82%	35.62%
Middle	55	4174	$340	2.17%	5.92%	13.31%	21.89%	24.95%
	56	4178	$340	9.50%	18.29%	34.69%	50.13%	58.98%
	57	4104	$340	2.12%	3.48%	5.28%	8.92%	10.84%
	58	4007	$340	1.05%	1.63%	2.78%	4.88%	5.75%
	59	4034	$335	2.33%	5.04%	10.62%	16.40%	19.35%
Bottom	113	4114	$250	1.68%	3.90%	8.03%	11.18%	13.19%
	114	4077	$229	2.06%	6.62%	14.75%	20.59%	24.33%
	115	4183	$210	2.04%	5.34%	9.43%	14.37%	15.90%
	116	4184	$210	7.88%	13.34%	19.54%	25.11%	27.52%
	117	4303	$193	1.88%	4.91%	10.48%	14.45%	16.47%

Table B5: Exploratory Analysis – Solar installations and home owners

	Rank	Postcode	Owners	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4155	288	90.8%	6.29%	10.57%	22.00%	37.14%	43.43%
	2	4156	786	88.9%	4.11%	8.54%	16.97%	29.82%	35.62%
	3	4037	2,037	85.9%	3.72%	7.68%	17.94%	28.24%	33.07%
	4	4035	6,452	84.1%	4.37%	8.82%	17.10%	26.55%	31.26%
	5	4069	9,048	83.6%	3.26%	6.58%	13.10%	19.68%	22.70%
Middle	55	4503	8,024	66.1%	2.29%	6.28%	14.02%	21.72%	26.34%
	56	4507	4,948	65.8%	4.34%	12.42%	21.01%	27.36%	30.34%
	57	4158	957	65.7%	3.14%	6.15%	11.56%	15.68%	17.90%
	58	4078	4,993	65.5%	2.99%	8.94%	17.64%	25.50%	29.20%
	59	4172	923	65.3%	2.75%	5.37%	12.50%	18.00%	20.42%
Bottom	113	4169	2,116	40.5%	0.71%	1.16%	2.19%	3.55%	4.24%
	114	4102	915	38.2%	1.79%	3.33%	6.77%	9.06%	10.46%
	115	4101	2,850	37.1%	1.27%	2.13%	3.83%	5.65%	6.25%
	116	4000	2,002	36.4%	0.33%	0.54%	0.76%	1.15%	1.43%
	117	4006	2,292	34.5%	0.18%	0.37%	0.76%	1.24%	1.43%

Table B6: Exploratory Analysis – Solar installations and home renters

	Rank	Postcode	Renters	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4006	4,197	63.2%	0.18%	0.37%	0.76%	1.24%	1.43%
	2	4101	4,556	59.4%	1.27%	2.13%	3.83%	5.65%	6.25%
	3	4000	3,260	59.3%	0.33%	0.54%	0.76%	1.15%	1.43%
	4	4102	1,296	58.2%	1.79%	3.33%	6.77%	9.06%	10.46%
	5	4169	2,983	56.7%	0.71%	1.16%	2.19%	3.55%	4.24%
Middle	55	4163	1,918	33.2%	3.48%	7.60%	11.89%	17.33%	19.58%
	56	4078	2,515	33.0%	2.99%	8.94%	17.64%	25.50%	29.20%
	57	4133	1,626	33.0%	2.96%	8.86%	15.84%	22.18%	26.24%
	58	4111	112	32.7%	2.07%	5.18%	12.18%	16.32%	18.91%
	59	4018	1,163	32.0%	1.73%	5.26%	12.12%	18.42%	21.98%
Bottom	113	4125	320	13.6%	3.38%	8.86%	18.93%	27.22%	31.69%
	114	4037	306	12.9%	3.72%	7.68%	17.94%	28.24%	33.07%
	115	4035	985	12.8%	4.37%	8.82%	17.10%	26.55%	31.26%
	116	4156	83	9.4%	4.11%	8.54%	16.97%	29.82%	35.62%
	117	4155	25	7.9%	6.29%	10.57%	22.00%	37.14%	43.43%

The results of the exploratory analysis of solar PV installations and median weekly income (Table B2) did not appear to support the findings of previous literature. Individual postcodes within each of the five upper, middle and bottom cohorts had significant uptake of solar PV despite significant differences in median weekly income. The results of the exploratory analysis of solar PV installations and mortage payments (Table B3) also did not support the findings of previous literature with the middle five postcode cohort having a consistently higher uptake of solar PV than the upper cohort. The results of the exploratory analysis of solar PV installations and weekly rent (Table B4) was inconclusive whereas the results from the analysis of solar PV installations and home owners (Table B5) and the analysis of solar PV installations and home renters (Table B6) supported the findings of previous literature. The summary figures in Table B5 indicate that home ownership is a critical factor in solar PV installation which supports previous research and literature (Macintosh & Wilkinson, 2011). Tables B6 and B14 indicate a relationship between areas with the highest concentrations of persons who rented or lived in apartments and lower rates of solar PV installations. This would appear to further support a positive correlation between home ownership and PV installation.

Table B7: Exploratory Analysis - Solar installations and Families of two or more persons

	Rank	Postcode	Families	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4305	15,118	2.41%	5.91%	13.01%	19.83%	22.91%
	2	4207	12,839	3.73%	7.86%	14.73%	21.20%	24.65%
	3	4300	12,100	2.70%	6.54%	13.80%	21.01%	25.00%
	4	4053	11,589	2.24%	4.81%	9.37%	15.09%	17.52%
	5	4152	11,572	2.92%	5.73%	10.73%	16.61%	19.11%
Middle	55	4159	3,841	5.65%	10.95%	19.44%	28.03%	31.97%
	56	4171	3,765	1.19%	2.49%	5.32%	8.97%	10.41%
	57	4032	3,719	1.26%	3.00%	5.93%	9.48%	11.09%
	58	4054	3,714	2.86%	6.22%	12.40%	18.56%	21.69%
	59	4151	3,676	1.40%	2.47%	4.80%	7.69%	9.02%
Bottom	113	4117	303	1.64%	6.54%	18.22%	23.60%	27.10%
	114	4155	293	6.29%	10.57%	22.00%	37.14%	43.43%
	115	4106	279	3.65%	6.75%	12.96%	19.89%	24.27%
	116	4111	229	2.07%	5.18%	12.18%	16.32%	18.91%
	117	4008	79	1.38%	3.45%	6.21%	11.03%	12.41%

Previous literature did not identify the significance of family composition in the uptake of solar PV. Although the results of the exploratory analysis of solar PV installations and families of two or more persons (Table B7) was inconclusive, it provided indicators that family composition may be an important explanatory variable.

Previous research by (Caird, et al., 2008) indicated that knowledge was a critical feature in solar PV decisions. However, the results of the comparative analysis of solar PV installations and Tertiary Education (Table B8) showed the postal areas with highest uptake of solar PV had the lowest levels of university/tertiary education. Table B6 identified very low rates of installation of solar PV in postal areas with the highest numbers of university/tertiary educated persons, whereas the areas with the lowest levels of university/tertiary educated persons had more than double the installation rates of solar PV. However, the postal areas with the highest numbers of university/tertiary educated persons were also areas with high concentration of units and apartments.

Table B8: Exploratory Analysis - Solar installations and Tertiary Education

	Rank	Postcode	Education University/ Tertiary	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4111	561	72.2%	2.07%	5.18%	12.18%	16.32%	18.91%
	2	4067	3,462	70.1%	1.11%	1.80%	3.17%	5.00%	5.67%
	3	4066	3,174	52.7%	1.22%	2.03%	3.50%	5.34%	5.98%
	4	4059	2,303	51.7%	1.30%	2.45%	4.56%	7.02%	7.93%
	5	4068	3,846	46.5%	1.46%	2.55%	4.98%	7.76%	9.08%
Middle	55	4119	251	15.6%	3.55%	8.99%	19.89%	30.42%	35.51%
	56	4055	905	15.3%	4.00%	8.55%	16.63%	25.44%	29.63%
	57	4123	667	14.8%	3.20%	7.91%	15.27%	23.01%	27.55%
	58	4054	516	14.7%	2.86%	6.22%	12.40%	18.56%	21.69%
	59	4130	338	14.3%	5.40%	10.62%	21.85%	33.09%	37.74%
Bottom	113	4303	74	5.4%	1.88%	4.91%	10.48%	14.45%	16.47%
	114	4508	321	5.3%	2.51%	6.39%	12.62%	19.04%	22.72%
	115	4114	601	5.3%	1.68%	3.90%	8.03%	11.18%	13.19%
	116	4132	363	4.9%	2.64%	7.08%	15.75%	21.58%	25.10%
	117	4184	70	4.5%	7.88%	13.34%	19.54%	25.11%	27.52%

Anecdotal information indicated that many of the persons acquiring solar PV were older adults who saw the $0.44 FiT as an opportunity to manage electricity bills into the future. A exploratory analysis of the explanatory variables *being aged over 55 years* and *being aged over 65 years* is provided in Tables B9 and B10. Both of these tables show the postcode with the lowest numbers of people aged over 55 an 65 years respectively (postcode 4178) had a significant uptake of solar PV. Conversely, the postcode with the greatest numbers of people aged over 55 an 65 years respectively (postcode 4507) recorded significant uptakes of solar PV. However, the results are deemed as being inconclusive as each of the three cohorts (upper, middle and bottom) have postcode areas with significant uptakes of solar PV.

Table B9: Exploratory Analysis - Solar installations and people aged over 55 years

	Rank	Postcode	Aged over 55 years	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4507	9041	53.04%	4.34%	12.42%	21.01%	27.36%	30.34%
	2	4184	2955	46.60%	7.88%	13.34%	19.54%	25.11%	27.52%
	3	4163	5411	37.54%	3.48%	7.60%	11.89%	17.33%	19.58%
	4	4183	760	37.51%	2.04%	5.34%	9.43%	14.37%	15.90%
	5	4179	6631	36.53%	4.07%	7.35%	13.78%	19.81%	22.38%
Middle	55	4104	1226	22.13%	2.12%	3.48%	5.28%	8.92%	10.84%
	56	4156	658	22.07%	4.11%	8.54%	16.97%	29.82%	35.62%
	57	4153	1012	22.03%	3.53%	6.26%	14.62%	23.54%	26.70%
	58	4121	5222	21.96%	2.29%	4.21%	8.45%	13.75%	16.16%
	59	4117	265	21.90%	1.64%	6.54%	18.22%	23.60%	27.10%
Bottom	113	4132	3043	13.53%	2.64%	7.08%	15.75%	21.58%	25.10%
	114	4059	1535	13.28%	1.30%	2.45%	4.56%	7.02%	7.93%
	115	4301	3022	13.02%	2.53%	6.53%	13.31%	20.29%	23.66%
	116	4006	2205	12.44%	0.18%	0.37%	0.76%	1.24%	1.43%
	117	4178	1099	4.58%	9.50%	18.29%	34.69%	50.13%	58.98%

Table B10: Exploratory Analysis - Solar installations and people aged over 65 years

	Rank	Postcode	Aged over 65 years	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4507	7778	45.63%	4.34%	12.42%	21.01%	27.36%	30.34%
	2	4184	2363	37.27%	7.88%	13.34%	19.54%	25.11%	27.52%
	3	4111	466	33.36%	2.07%	5.18%	12.18%	16.32%	18.91%
	4	4163	4299	29.83%	3.48%	7.60%	11.89%	17.33%	19.58%
	5	4205	1357	29.57%	3.90%	10.47%	22.27%	27.55%	31.40%
Middle	55	4011	2443	16.94%	1.11%	2.26%	4.33%	7.36%	8.63%
	56	4035	3930	16.87%	4.37%	8.82%	17.10%	26.55%	31.26%
	57	4073	1571	16.84%	3.56%	9.24%	18.73%	26.35%	30.88%
	58	4130	1335	16.62%	5.40%	10.62%	21.85%	33.09%	37.74%
	59	4105	2130	16.60%	1.71%	3.23%	7.15%	10.91%	12.70%
Bottom	113	4154	838	9.08%	2.58%	6.95%	15.76%	26.59%	31.78%
	114	4000	1268	8.85%	0.33%	0.54%	0.76%	1.15%	1.43%
	115	4006	1516	8.55%	0.18%	0.37%	0.76%	1.24%	1.43%
	116	4301	1968	8.48%	2.53%	6.53%	13.31%	20.29%	23.66%
	117	4178	743	3.10%	9.50%	18.29%	34.69%	50.13%	58.98%

Table B11: Exploratory Analysis - Solar installations and private homes

	Rank	Postcode	Private homes	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4305	23,230	2.41%	5.91%	13.01%	19.83%	22.91%
	2	4207	18,234	3.73%	7.86%	14.73%	21.20%	24.65%
	3	4034	17,218	2.33%	5.04%	10.62%	16.40%	19.35%
	4	4053	17,202	2.24%	4.81%	9.37%	15.09%	17.52%
	5	4510	17,136	2.89%	6.74%	13.52%	19.33%	23.09%
Middle	55	4171	6,302	1.19%	2.49%	5.32%	8.97%	10.41%
	56	4123	6,255	3.20%	7.91%	15.27%	23.01%	27.55%
	57	4115	6,114	3.37%	8.37%	19.20%	28.93%	34.23%
	58	4124	6,077	5.08%	11.52%	22.30%	32.17%	37.06%
	59	4161	6,072	3.92%	8.86%	17.03%	25.72%	29.61%
Bottom	113	4106	548	3.65%	6.75%	12.96%	19.89%	24.27%
	114	4117	428	1.64%	6.54%	18.22%	23.60%	27.10%
	115	4111	386	2.07%	5.18%	12.18%	16.32%	18.91%
	116	4155	350	6.29%	10.57%	22.00%	37.14%	43.43%
	117	4008	145	1.38%	3.45%	6.21%	11.03%	12.41%

A finding from previous research was the link between private home ownership and solar PV (Byrnes et al., 2013; Grösche & Schröder, 2014; Macintosh & Wilkinson, 2011; Nelson et al., 2012). This is based on the assumption that persons renting would be unlikely to make such a capital investment to a property they did not own and that owners of rental properties would not be installing solar PV as they had no obligation for electricity used by their tenants. The exploratory analysis undertaken by this research project found evidence to suppport this.

Table B12 shows high levels of solar PV uptake in the upper cohort with the most detached houses. Conversely, Table B12 shows very low levels of solar PV uptake in the lower cohort with the fewest detached houses. The result from the comparative analysis for semi-detached houses/townhouses (Table B13) was inconclusive.

Table B12: Exploratory Analysis - Solar installations and detached houses

	Rank	Postcode	Detached Houses	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4155	317	100.0%	6.29%	10.57%	22.00%	37.14%	43.43%
	2	4036	2,390	99.7%	2.36%	5.72%	14.74%	21.96%	26.13%
	3	4037	2,349	99.1%	3.72%	7.68%	17.94%	28.24%	33.07%
	4	4184	2,755	98.9%	7.88%	13.34%	19.54%	25.11%	27.52%
	5	4504	4,802	98.5%	4.24%	10.08%	21.39%	33.15%	39.05%
Middle	55	4133	4,237	86.1%	2.96%	8.86%	15.84%	22.18%	26.24%
	56	4510	12,737	86.0%	2.89%	6.74%	13.52%	19.33%	23.09%
	57	4053	13,467	85.9%	2.24%	4.81%	9.37%	15.09%	17.52%
	58	4508	5,704	85.3%	2.51%	6.39%	12.62%	19.04%	22.72%
	59	4065	2,759	85.0%	2.51%	4.41%	8.15%	12.87%	14.63%
Bottom	113	4169	1,575	30.1%	0.71%	1.16%	2.19%	3.55%	4.24%
	114	4005	1,114	21.4%	0.64%	1.10%	2.21%	3.66%	4.04%
	115	4006	796	12.0%	1.05%	1.63%	2.78%	4.88%	5.75%
	116	4007	796	12.0%	0.18%	0.37%	0.76%	1.24%	1.43%
	117	4000	626	11.4%	0.33%	0.54%	0.76%	1.15%	1.43%

Table B13: Exploratory Analysis - Solar installations and semi-detached houses/townhouses

	Rank	Postcode	Semi-detached homes	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4158	355	24.4%	3.14%	6.15%	11.56%	15.68%	17.90%
	2	4163	1,369	23.7%	3.48%	7.60%	11.89%	17.33%	19.58%
	3	4113	2,027	22.1%	2.69%	7.83%	16.85%	23.96%	27.23%
	4	4018	769	21.2%	1.73%	5.26%	12.12%	18.42%	21.98%
	5	4022	429	19.3%	3.05%	8.84%	16.65%	22.60%	26.38%
Middle	55	4030	516	8.4%	1.38%	2.46%	4.96%	8.04%	9.03%
	56	4064	336	8.4%	1.52%	2.58%	4.79%	7.67%	8.60%
	57	4119	145	8.3%	3.55%	8.99%	19.89%	30.42%	35.51%
	58	4010	74	8.1%	0.67%	2.19%	4.10%	6.95%	7.81%
	59	4035	611	8.0%	4.37%	8.82%	17.10%	26.55%	31.26%
Bottom	113	4036	3	0.1%	2.36%	5.72%	14.74%	21.96%	26.13%
	114	4155	0	0.0%	6.29%	10.57%	22.00%	37.14%	43.43%
	115	4184	0	0.0%	7.88%	13.34%	19.54%	25.11%	27.52%
	116	4111	0	0.0%	2.07%	5.18%	12.18%	16.32%	18.91%
	117	4008	0	0.0%	1.38%	3.45%	6.21%	11.03%	12.41%

Further evidence of the link between private home ownership and solar PV is identified by Table B14 which outlines the suburbs with differing concentrations of apartments and units. Anecdotal evidence indicated that these types of dwellings were unable to access solar PV as solar PV often requires direct access to a rooftop which may not be otherwise available in these dwelling types. In addition to this, many apartments and units are used for the rental market and, as stated previously, landlords would have few incentives to provide their tenants with solar PV. The exploratory analysis undertaken by this research project found evidence to suppport this. An examination of Table B12 shows high levels of solar PV uptake in the upper cohort with the most detached houses. Conversely, Table B6 (Renters) and Table B14 (Units, Flats and Apartments) indicate that a number of postal areas with the highest numbers of renters (4000, 4006, 4169) also have the highest concentrations of Units, Flats and Apartments. In the case of Table B14, it shows very low levels of solar PV uptake in the upper cohort with the most Units, Flats and Apartments and very high levels of of solar PV uptake in the lower cohort with the fewest Units, Flats and Apartments.

Table B14: Exploratory Analysis - Solar installations and Units, Flats, Apartments

	Rank	Postcode	Units, Flats, Apartments	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4000	4,593	83.6%	0.33%	0.54%	0.76%	1.15%	1.43%
	2	4006	5,472	82.4%	0.18%	0.37%	0.76%	1.24%	1.43%
	3	4007	5,472	82.4%	1.05%	1.63%	2.78%	4.88%	5.75%
	4	4005	3,681	70.8%	0.64%	1.10%	2.21%	3.66%	4.04%
	5	4169	3,318	63.5%	0.71%	1.16%	2.19%	3.55%	4.24%
Middle	55	4157	277	4.2%	3.80%	8.30%	16.16%	23.52%	27.11%
	56	4305	864	4.2%	2.41%	5.91%	13.01%	19.83%	22.91%
	57	4021	146	4.0%	2.51%	6.03%	13.17%	18.71%	22.95%
	58	4173	125	4.0%	2.98%	6.91%	13.95%	20.39%	23.88%
	59	4054	175	3.6%	2.86%	6.22%	12.40%	18.56%	21.69%
Bottom	113	4164	4	0.1%	5.00%	10.25%	18.54%	29.02%	33.70%
	114	4117	0	0.0%	1.64%	6.54%	18.22%	23.60%	27.10%
	115	4130	0	0.0%	5.40%	10.62%	21.85%	33.09%	37.74%
	116	4154	0	0.0%	2.58%	6.95%	15.76%	26.59%	31.78%
	117	4155	0	0.0%	6.29%	10.57%	22.00%	37.14%	43.43%

The evidence of the link between type of dwelling and solar PV uptake is further identified in Table 5B14 which examined the number of bedrooms in a dwelling. The basis of this examination is that dwellings with three or more bedrooms are most likely to be a detached house or large semi-detached dwellings with greater access to rooftops. Table B15 indicates significant levels of solar PV uptake in the upper cohort with the most homes with three or more bedrooms and very low levels of of solar PV uptake in the lower cohort with the fewest dwellings with three or more bedrooms. Further evidence to support this is in Table B15 in which postcode areas with the fewest dwellings with three or more bedrooms (4000, 4006, 4101, 4169) are also the areas with the highest levels of Units, Flats and Apartments (4000, 4006, 4101, 4169) in Table B6.

Table B15: Exploratory Analysis - Solar installations and homes with three or more bedrooms

	Rank	Postcode	Three plus bedrooms	%	Solar 2010 (%)	Solar 2011 (%)	Solar 2012 (%)	Solar 2013 (%)	Solar 2014 (%)
Top	1	4037	2,328	98.2%	3.72%	7.68%	17.94%	28.24%	33.07%
	2	4154	2,781	97.5%	2.58%	6.95%	15.76%	26.59%	31.78%
	3	4116	6,933	97.1%	3.03%	9.87%	22.42%	31.74%	36.23%
	4	4504	4,729	97.0%	4.24%	10.08%	21.39%	33.15%	39.05%
	5	4070	3,293	96.4%	4.37%	8.76%	17.55%	26.59%	31.84%
Middle	55	4076	1,246	83.6%	2.13%	5.92%	13.67%	20.36%	24.26%
	56	4018	2,667	83.5%	1.73%	5.26%	12.12%	18.42%	21.98%
	57	4157	5,556	83.4%	3.80%	8.30%	16.16%	23.52%	27.11%
	58	4505	5,261	83.1%	4.69%	10.80%	20.88%	31.52%	36.61%
	59	4152	12,733	83.0%	2.92%	5.73%	10.73%	16.61%	19.11%
Bottom	113	4169	2,176	41.6%	0.71%	1.16%	2.19%	3.55%	4.24%
	114	4101	2,915	38.0%	1.27%	2.13%	3.83%	5.65%	6.25%
	115	4005	1,718	33.1%	0.64%	1.10%	2.21%	3.66%	4.04%
	116	4006	1,779	26.8%	0.18%	0.37%	0.76%	1.24%	1.43%
	117	4000	143	26.0%	0.33%	0.54%	0.76%	1.15%	1.43%

Based on the above results of exploratory assessment undertaken on the quantitative data for this research, a number of issues of significance were identified:

- the links between private home ownership and solar PV uptake were supported;
- that tertiary education did not appear to be as significant as identified by previous literature;
- that financial capacity did not appear to be as significant as identified by previous literature;
- anecdotal links between solar PV uptake and being aged over 55 years or aged over 65 years were inconclusive;

- the number of bedrooms of home was a significant explanatory variable in solar PV uptake;
- the type of dwelling was a significant explanatory variable for solar PV uptake.

Decision tree analysis

The exploratory assessment of demographic explanatory variables and solar PV installation data identified a number of issues of significance and a further analysis of the information was undertaken using statistical software to remove potential analysis bias. This statistical analysis was performed using decision trees, obtained via the RPART and GBM packages in the free R software which is widely used for statistical analysis, classification and clustering (http://www.r-project.org/). Decision models are general purpose prediction and classification mechanisms that are used in a range of data mining and knowledge discovery (de Ville, 2013). These models provide a simple to understand representation of the relationship between a response variable (solar PV) and potential explanatory variables and are accepted in many fields of research because they can identify and interpret complex hierarchical relationships (Hu, *et al*., 2011).

Two types of trees were used in this research: a) classification and regression tree analysis (CART) and; b) boosted regression tree analysis (BRT):

Classification and regression tree analysis (CART)

The first type was a classification and regression tree (CART) that is a flowchart-like structure with branches that represent a split in the dataset based on the displayed decision rule, and final nodes show the characteristics of the corresponding subset of observations. Figures B1 to B5 (below) show the decision trees developed for this project.

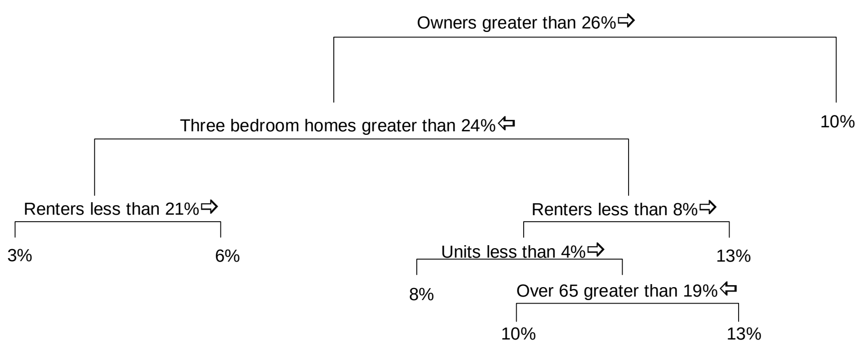

Figure B1: Classification and regression tree for 2010

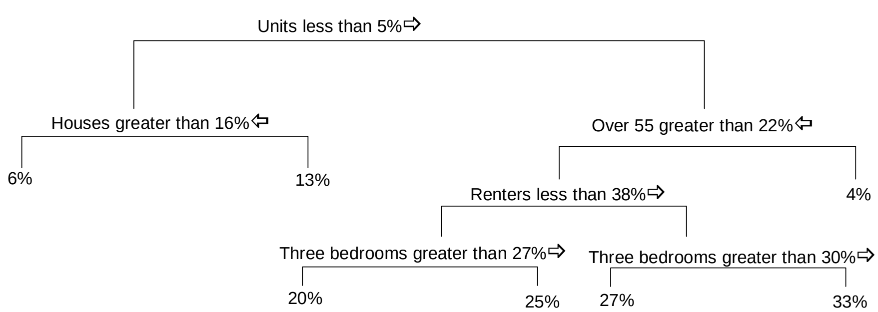

Figure B2: Classification and regression tree for 2011

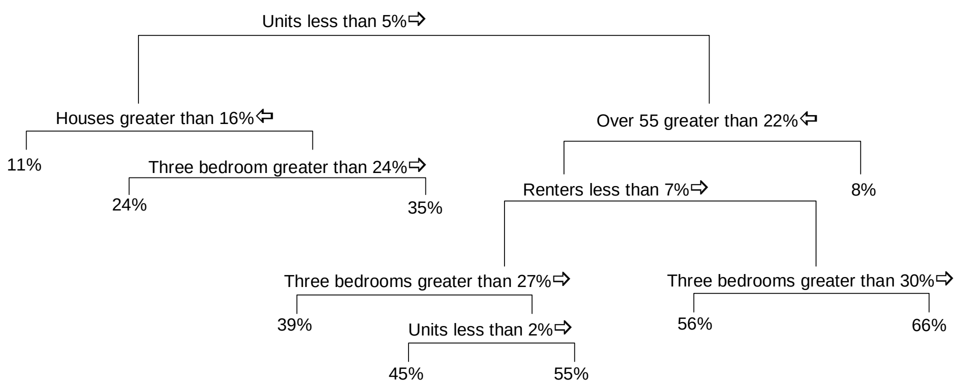

Figure B3: Classification and regression tree for 2012

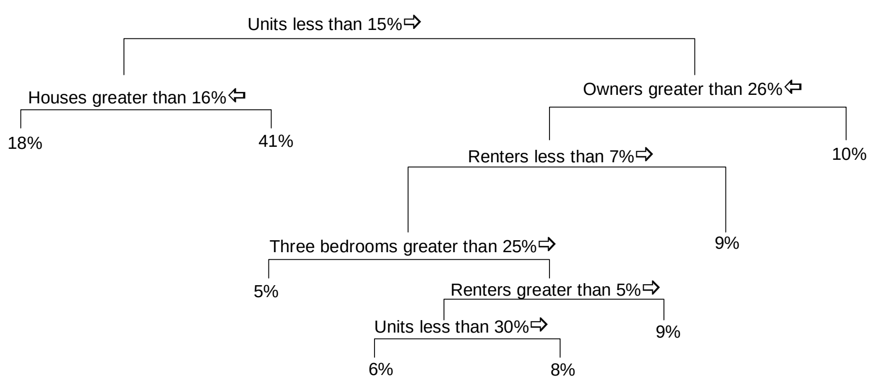

Figure B4: Classification and regression tree for 2013

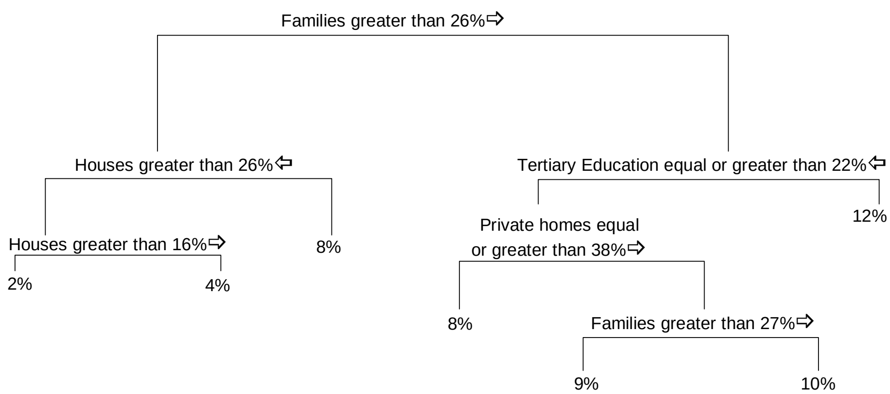

Figure B5: Classification and regression tree for 2014

The CART analysis showed at the mid-point of the $0.44 solar FiT policy (July 2010), the most significant demographic feature in the uptake of solar PV was families of two or more persons. The CART summary (Table B16) identified that the strongest differentiation in solar uptake was people aged over 55 years, followed by persons who owned their own homes and privately owned dwellings.

Table B16: CART significance of explanatory variables as ranked by R program

Significance	July 2010	July 2011	July 2012	July 2013	July 2014
1	Families	Families	Three Bedrooms	Three Bedrooms	Families
2	Over 55	Over 55	Over 55	Families	Houses
3	Houses	Houses	Houses	Houses	Education
4	Owners	Private homes	Private homes	Education	Private homes
5	Private homes		Owners	Private homes	

However, by July 2012, when $0.44 solar FiTs ended in Queensland, the most significant explanatory variable impacting on solar PV uptake was the size of the dwellings with three or more bedrooms, with people aged over 55 years continuing to be a strong explanatory variable.

Four of the five strongest explanatory variables in 2012 related to the type of dwelling or its ownership. By 2014, two years after the end of $0.44 solar FiTs the primary explanatory variable was families of two or more persons, with education emerging as an important explanatory variable.

Boosted regression tree analysis (BRT)

The second type of statistical analysis performed were boosted regression trees (BRT) which show the relative influence of the demographic variables. Figures B6 to B10 (below) show the BRTs developed for this project.

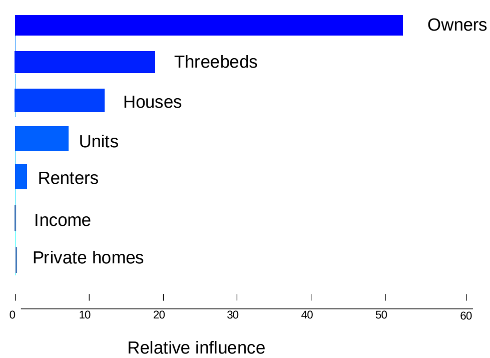

Figure B6: Boosted regression tree for 2010

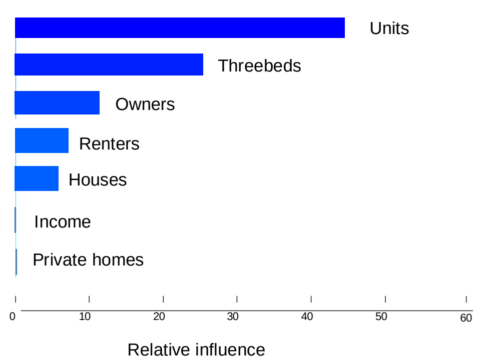

Figure B7: Boosted regression tree for 2011

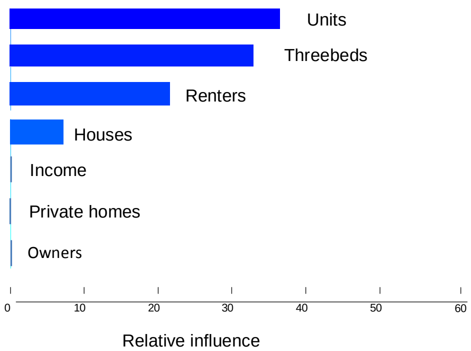

Figure B8: Boosted regression tree for 2012

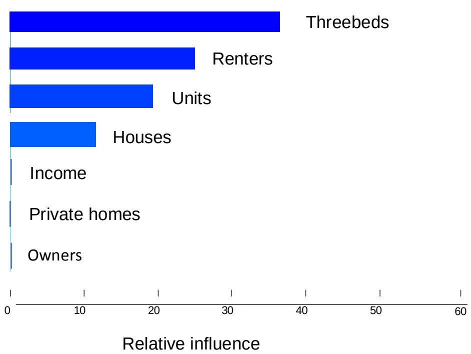

Figure B9: Boosted regression tree for 2013

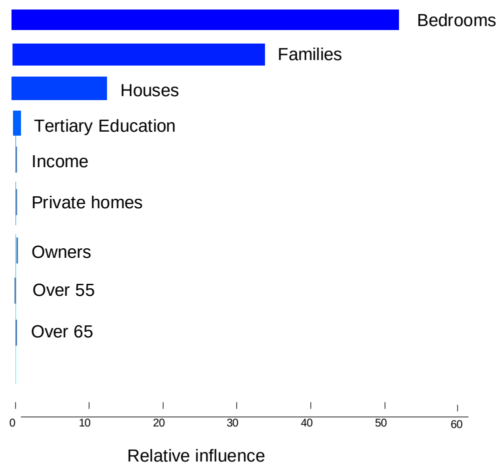

Figure B10: Boosted regression tree for 2014

The BRT examination of the relative influence of the explanatory variables as predictors shows that dwellings with three or more bedrooms, families of two or more person and houses reoccurred in most years. A summary of the five years is outlines in Figure B11 below. The BRT results generally correlated with the explanatory variables in the CART analysis.

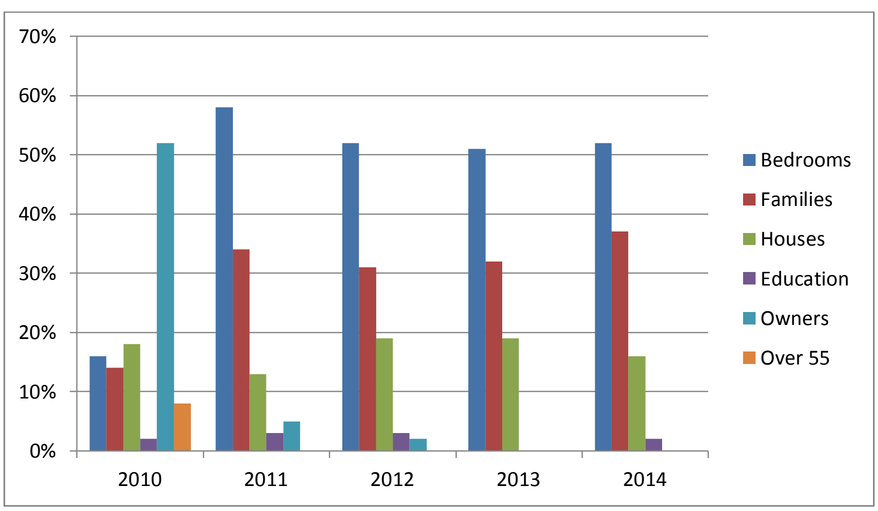

Figure B11: Summary of boosted regression tree relative influence 2010 to 2014

Synthesis

The synthesis of the quantitative analysis was undertaken to triangulate the different qualitative methods using an *exploratory factor analysis* which is a process of creating groups of variables that have high correlations with other groups of variables (Tashakkori & Teddlie, 2003). An exploratory factor analysis assesses:

- convergent validity (high correlation with each explanatory variable); and
- discriminant validity (low correlation with each explanatory variable) (Neuman, 2011).

The CART and BRT analyses highlighted the inter-relationship between the explanatory variables indicating that combination of issues can be significant in determining the influence of socio-economic factors on the uptake of the response variable, solar PV. The analysis of this study identified a number of issues of significance:

- the CART analysis identified that being over 55 years old was a significant explanatory variable in solar PV uptake;
- the CART analysis identified that family composition of a household was a significant explanatory variable in solar PV uptake;
- the CART analysis identified that the number of bedrooms of residential homes was a significant explanatory variable in solar PV uptake;
- the BRT analysis identified that the number of bedrooms of home was a significant explanatory variable;
- the BRT analysis identified that the family composition of households was a significant explanatory variable;
- the BRT analysis identified that the type of dwelling (houses) was a significant explanatory variable; and
- the synthesis of the decision tree analysis identified the linkage of explanatory variables in solar PV uptake.

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Appendix: C

	PARTICIPANT INFORMATION FOR QUT RESEARCH PROJECT – Interview –

Motivational and contextual factors involved in decision-making of residential customers to adopt or not adopt solar energy technology

QUT Ethics Approval Number 1400000991

RESEARCH TEAM

Principal Researcher:	Jeff Sommerfeld	PhD Student
Associate Researcher:	Prof Laurie Buys	Principal Supervisor
	School of Design, Creative Industries Faculty, Queensland University of Technology (QUT)	

DESCRIPTION

This project is being undertaken as part of a PhD for the above researcher. The purpose of this research is to understand the decisions of people to purchase or not purchase domestic rooftop solar electricity systems.

Almost 11 per cent of the Australia population (about 2.6 million people) now use solar for their electricity but that also means almost 89 per cent of the Australian population have not participated to date under circumstances where policies actively encouraged and provided generous financial incentives to uptake solar photovoltaic (PV) technology. The key research aim of this project is to understand the motivations and actions of the 89 per cent of the population that have not acquired solar energy technology to identify potential policy barriers that may be impeding participation.

This research aims to identify the motivational and contextual factors involved in the decision-making of residential customers to adopt or not adopt renewable energy technology. This research will examine consumer choices, knowledge and behavior regarding solar technology. The final outcome of this research is to identified barriers and obstacles that may impede community participation in energy demand management, energy efficiency and renewable energy programs.

You are invited to participate in this project because you have indicated you are available.

PARTICIPATION

Your participation will involve an audio recorded interview at either your home or other agreed location that will take approximately one hour of your time. Questions will include:

- What is your understanding of the personal benefits of solar PV?
- What were the barriers that prevented you from acquiring it?
- What would you need to have or know that would enable you to acquire rooftop solar PV?

Your participation in this project is entirely voluntary. If you do agree to participate you can withdraw from the project at any time during the project. Your decision to participate or not participate will in no way impact upon your current or future relationship with QUT.

EXPECTED BENEFITS

It is expected that this project will not benefit you directly. However, it may benefit our community through a better understanding of public understanding and acceptance of renewable energy products. This knowledge can help guide future development of policies and programs.

RISKS

There are no risks beyond normal day-to-day living associated with your participation in this project. You can skip any questions you do not wish to answer.

PRIVACY AND CONFIDENTIALITY

All comments and responses will be treated confidentially unless required by law.

The interview will be recorded on an audio recorder for the purposes of accurate records of your comments. After the interview a record of your interview will be prepared from the recording and the recording will then be deleted. The record of interview will be edited to remove your name or any information that could identify you. Should you wish to not have the interview recorded your comments will be written down during the interview.

All records associated with this project will be secured and only available to the research team. Upon completion any records will be retained for five (5) years for audit purposes only.

CONSENT TO PARTICIPATE

We would like to ask you to sign a written consent form (enclosed) to confirm your agreement to participate.

QUESTIONS / FURTHER INFORMATION ABOUT THE PROJECT

If have any questions or require further information please contact one of the research team members below.

Jeff Sommerfeld	j.sommerfeld@qut.edu.au
Laurie Buys	l.buys@qut.edu.au

CONCERNS / COMPLAINTS REGARDING THE CONDUCT OF THE PROJECT

QUT is committed to research integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the project you may contact the QUT Research Ethics Unit on 3138 5123 or email ethicscontact@qut.edu.au. The QUT Research Ethics Unit is not connected with the research project and can facilitate a resolution to your concern in an impartial manner.

Thank you for helping with this research project. Please keep this sheet for your information.

QUT Queensland University of Technology Brisbane Australia	**CONSENT FORM FOR QUT RESEARCH PROJECT** **– Interview –**

Motivational and contextual factors involved in decision-making of residential customers to adopt or not adopt solar energy technology

QUT Ethics Approval Number 1400000991

RESEARCH TEAM CONTACTS

Jeff Sommerfeld	j.sommerfeld@qut.edu.au
Laurie Buys	l.buys@qut.edu.au

STATEMENT OF CONSENT

By signing below, you are indicating that you:

- Have read and understood the information document regarding this project.
- Have had any questions answered to your satisfaction.
- Understand that if you have any additional questions you can contact the research team.
- Understand that you are free to withdraw at any time, without comment or penalty.
- Understand that you can contact the Research Ethics Unit on 3138 5123 or email ethicscontact@qut.edu.au if you have concerns about the ethical conduct of the project.
- Agree to participate in the project.

Please tick the relevant box below:

☐ I **agree** for the interview to be audio-recorded.

☐ I **do not agree** for the interview to be audio-recorded.

Name ____

Signature ____

Date ____

MEDIA RELEASE PROMOTIONS

From time to time, we may like to promote our research to the general public through, for example, newspaper articles. Would you be willing to be contacted by QUT Media and Communications for possible inclusion in such stories? By ticking this box, it only means you are choosing to be contacted – you can still decide at the time not to be involved in any promotions.

☐ Yes, you may contact me about inclusion in promotions.

☐ No, I do not wish to be contacted about inclusion in promotions.

Please return this sheet to the investigator.